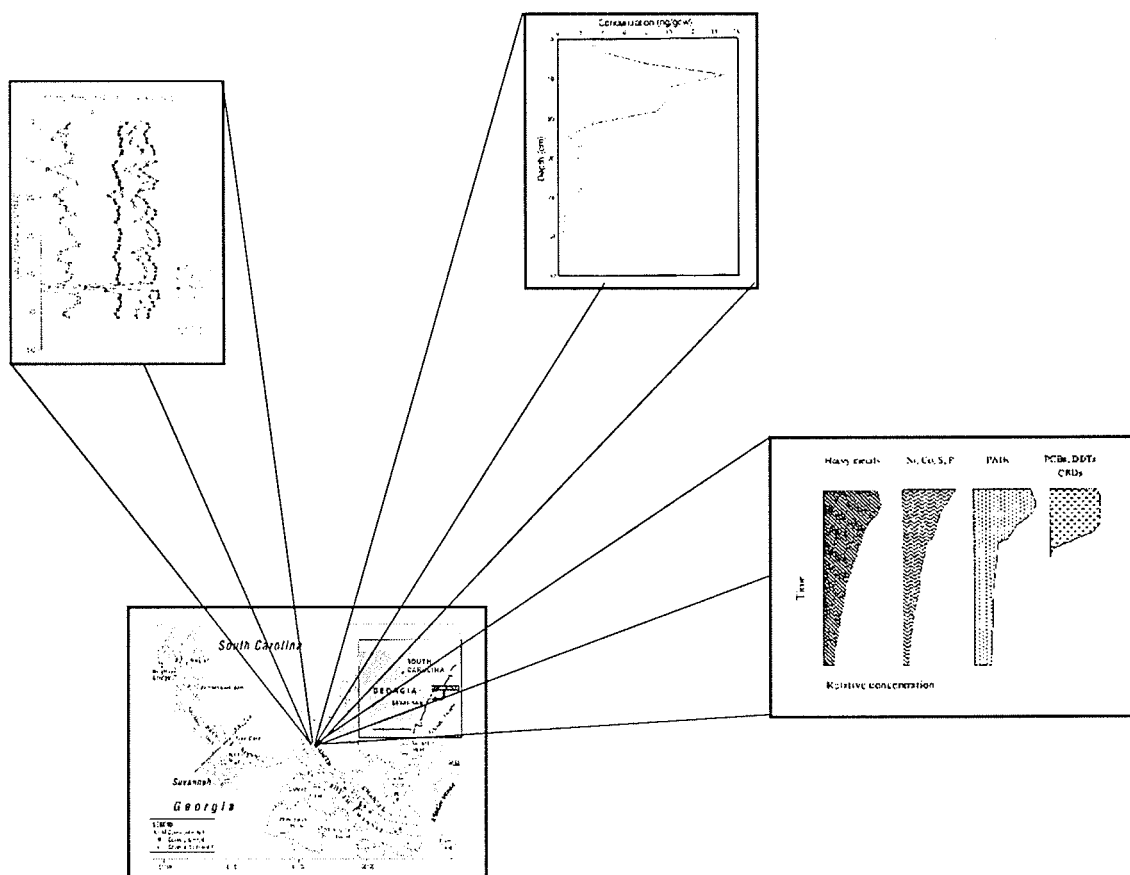**National Status and Trends Program**
for Marine Environmental Quality

Pollution History of the Savannah Estuary

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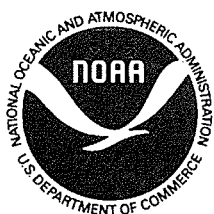Silver Spring, MD 20910

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Pollution History of the Savannah Estuary

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The National Oceanic and Atmospheric Administration
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Core Project Report Series

Foreword
by Nathalie Valette-Silver

Historical trends in contamination of estuarine and coastal sediments:

The composition of surface waters in rivers, lakes, and coastal areas has changed over time. In particular, changes due to the Industrial Revolution, dating from the middle of the last century, are very well known. These changes are expressed by increased levels of natural components, such as trace metals and nutrients, but also by the increase of anthropogenic compounds, such as polychlorinated biphenyls (PCBs) and pesticides.

Since the early 1960's, regulatory measures have been taken to decrease the amount of pollutants entering our waterways, but the bulk of these environmental measures were not enacted until the 1970's. Because of the scarcity of accurate data, due to the lack of sensitive techniques or of regular data collection in the past, the extent of the past pollution and the effect of the recent legislative limitations is often difficult to assess.

The analysis of sediment cores presents a way out of this dilemma. Most pollutants have an affinity for and adsorb easily onto sediments and fine particles. Therefore, by analyzing cores of undisturbed sediments it is possible to assess the historic pollution of a given system. Sediment cores reflect not only the history of pollutant concentrations but also register the changes in the ecology of a water body. For example, changes in estuarine eutrophication are reflected in the concentration of organic matter, nitrogen, and phosphorous, while lake acidification is translated into changes in diatom assemblages.

The use of cored sediments to reconstruct the chronology of coastal and estuarine contamination is not, however, devoid of problems and caution must be exercised. Sediment mixing by physical or biological processes can obscure the results obtained by such studies, and sophisticated methods must be used in these cases to tease out the desired information.

The NS&T Core Project

Between 1989 and 1996, the National Status and Trends Program sponsored research that gathered information on long term trends in contamination of US coastal and estuarine sediments. In this project, ten areas have been targeted. They include:

1) On the East coast:
- •Hudson/ Raritan estuary
- •Long Island Sound marshes
- •Chesapeake Bay
- •Savannah Estuary

2) On the Gulf coast:
- •Tampa Bay
- •Mississippi River Delta
- •Galveston Bay

3) On the West coast:
- •Southern California Bight
- •San Francisco Bay
- •Puget Sound

Presently, all the studies are completed and reports are, or will soon be, directly available from the cooperators. One of the most important results of the NS&T studies and of other similar studies reported in the literature, is the observed decline in recent years of many organic and inorganic contaminants in the sediments. It is very encouraging to know that mitigating measures taken in the 1970's have been

effective. This has shed a hopeful light on the potential success of future efforts to curb even more coastal and estuarine pollution.

In an effort to widely disseminate the results of these studies, the NS&T Prgram, in collaboration with the authors, is publishing some of the reports as NOAA Technical Memoranda. This study of the Savannah River Estuary area is the first one to be published in this series.

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EXECUTIVE SUMMARY

Dated cores collected from different sites in the Savannah Estuary were analyzed for 16 metals, 22 polycyclic aromatic hydrocarbons (PAH), 20 polychlorinated biphenyls (PCB) congeners, 16 pesticides and 3 butyltins. Time stratigraphy of the cores were determined by measurements of ^{210}Pb and ^{137}Cs activities down the cores. Those chemicals which showed significant temporal changes down dated cores in the Savannah Estuary included mercury, lead, chromium, PAHs, DDT isomers and metabolites, PCBs and dieldrin. The changes were most pronounced in Core H which was from the most industrialized area of the Savannah Estuary and near the city of Savannah. There was a large increase in PAH concentrations in Core H from the 1949 layers to 1958 layers followed by a gradual decrease to the surface (1993). Fluoranthene, pyrene and perylene were the major PAHs in all cores. Chromium concentrations in Core H rose during the 1950s followed by a decrease in the late 1960s. In 1968 there was a sharp peak in mercury concentrations in Core H. Lead concentrations increased in the 1940s and 1950s followed by a decrease in the late 1960s. The increase in metal and PAH concentrations are likely due to the increased development of the port of Savannah in the 1950s and 1960s. The subsequent decrease in the concentration is presumably due to the effect of pollution controls applied to those industries, since industrial growth has continued up to the present.

PCBs peaked in 1967 in Core H, as well as in a second core (Core F) further down the Savannah River. This peak in PCB concentration correlated with the peak of PCB production and use in the period 1965 to 1970. The decrease in PCB concentrations correlated with the ban on PCB production in 1976 in the United States. The highest concentration of DDT isomers was found in Core H at a depth dated at 1967. This high DDT isomer concentration was felt to be correlated with the use of DDT during this period to control large populations of breeding mosquitoes on nearby Hutchinson Island. The peak in DDT isomer concentration in Core F was in 1984 and DDE was not detected in the 1967 layer in this core. Since the manufacture of DDT was banned in 1972, the presence of increasing amounts of DDT isomers at site F suggest the source may be sediments or soil exposed earlier to DDT spray with later transport down the river to site F. Several other contaminants (e.g. metals) exhibited peaks in more recent strata in cores collected further downstream, away from the industrial areas. This also probably reflects redeposition of previously contaminated sediment.

Many of the past historical pollution studies have used dated cores from sites near densely populated and highly industrialized regions, (e.g. Boston Harbor, Puget Sound, Tokyo Bay). In contrast, the present study used cores from the Savannah Estuary, where the population is relatively low (approximately 150,000) and industrial growth has occurred over the past 30 years. Thus, the concentrations of most anthropogenic chemicals found in the cores of the Savannah Estuary were comparatively low. However, as noted above, temporal trends were apparent in Core H with respect to several anthropogenic chemicals while cores further down the Savannah River, (e.g. Core F), showed less pronounced temporal trends because of the very low concentrations of many anthropogenic chemicals. An interesting aspect of the study, which has been noted by many pollution history studies, was the decrease in the concentration of

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anthropogenic chemicals during the past two decades suggesting that many pollution control laws have been effective, even while industrial and population growth continues in an area.

In summation, our studies present evidence of relatively large inputs of anthropogenic chemicals, including mercury, chromium, lead, polycyclic aromatic hydrocarbons, dieldrin, DDT isomers, and polychlorinated biphenyls, during the 1950s and 1960s into the Savannah Estuary followed by a gradual decrease of these chemicals during the past 20 to 30 years.

Because of the report's size, and to facilitate the correlation of text and data for the reader, it has been divided into three volumes: Volume I - Text, Volume II - Figures and Tables (with the exception of Figure 1 which follows this Summary), and Volume III - Appendices.

1. INTRODUCTION

The Savannah Estuary is typical of the estuaries of the South Atlantic Bight formed within the mouths of Piedmont Rivers. The relatively high discharge of these rivers results in well-defined estuarine channels which provide favorable conditions for the development of ports. As a consequence, the estuaries of the Cape Fear, Pee Dee, Cooper and Savannah Rivers have been developed during the past 250 years into the ports of Wilmington, NC, Georgetown, SC, and Savannah, GA, respectively. Two other ports in the South Atlantic Bight, Jacksonville, FL, and Brunswick, GA are located in the estuaries of Coastal Plain Rivers.

Savannah has developed into one of the most important ports on the southeastern U.S. coast. At the present time, materials passing through the port include ores such as kaolin, coal and ferrous minerals, fuel oil, and other raw and processed chemicals. Many industries have developed around the port including paper, fertilizer, and chemical manufacturing.

How have the inputs of various contaminants to the Savannah Estuary changed during the past 100 years or more due to these anthropogenic changes? Have recent regulatory pollution-abatement activities been effective in reducing inputs? The results presented in this report provide information to help answer these questions. The study area and core locations are shown in Figure 1.

1.1   SEDIMENTATION IN THE SAVANNAH ESTUARY

Since 1950, the Savannah River has transported between 300 and 600 thousand metric tons of sediment annually (Meade, 1982). During the early 20th century (ca 1910), the annual flux was probably over a million metric tons. Virtually all of this sediment is trapped in the Savannah Estuary and was derived originally from the Southern Piedmont. As a result of row crop farming and deforestation, soil that had eroded from this region during the eighteenth and nineteenth centuries is still moving toward the estuary in the Savannah River. This material is periodically deposited and remobilized from flood plains, below the Clark Hill reservoir near Augusta, Georgia, as it moves down the river.

In addition to river input, the Savannah Estuary receives sediments from offshore (Meade, 1969). Continual resuspension of nearshore sediments winnows out fine particles which are subsequently transported shoreward and into the estuary in bottom water during flooding tides. Evidence for this is exhibited in sediment cores collected near the mouth of the Savannah River. These sediments exhibit increased concentrations of clay and silt size material with increasing depth (Windom et al., 1993). Other indicators of shoreward transport of material include 1) the distribution of trace minerals which are found in nearshore sediments but are derived from middle shelf sources (Schmitter and Freeman-Lynde, 1988), and 2) the enrichment of ^{210}Pb and oceanic plutonium in Savannah estuarine sediments which indicate offshore sources (Olsen et al., 1989).

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Areas of sediment accumulation on the shelf of the South Atlantic Bight are restricted to relatively small depositional sites within a few kilometers of shore and in front of barrier islands. Fine sediment previously deposited on the shelf during lower stands of sea level apparently has moved shoreward as the sea level rose, and the sediment has been deposited in estuaries.

Because of the increase in anthropogenically mobilized sediment and the influx of sediment from offshore sources in response to sea level rise, sedimentation rates in and adjacent to the Savannah Estuary are high. Sediments delivered to the Savannah Estuary accumulate in the major channels and tributaries, in adjacent salt marshes and in abandoned boat slips. Several salt marsh sites within the lower portion of the Savannah Estuary have been cored and accumulation rates have been measured using the ^{210}Pb method. Bottom sediments in tributaries immediately adjacent to the main channel and out of the influence of maintenance dredging (i.e., south channel, Figure 1) have accumulation rates of ca. 0.5-1.5 cm/yr (Goldberg et al., 1979; Alexander unpub. data). On the southern end of Turtle Island, Storti (1980) determined accumulation rates for salt marsh sediments to be from 5.6 to 7.6 cm/yr. These high rates result because the southern portions of barrier islands of the South Atlantic Bight prograde as the northern portions are eroded.

Several boat slips associated with shipping terminals on Hutchinson Island have been abandoned for over 50 years. The eastern two shown in Figure 1 were partially abandoned ca. 1917 and completely abandoned in 1925 (U.S. Army Corps of Engineers, pers. comm.). Subsequent to abandonment, these boat slips have remained undisturbed and have rapidly accumulated sediment such that the sediment-water interface in the slips is now intertidal. Many of these areas now support salt marsh vegetation and should preserve a continuous sediment record of at least four meters covering a time period of about six decades. In addition, these sediments are derived solely from the Savannah River Estuary and thus accurately reflect conditions within the estuary.

1.2   CONTAMINATION HISTORIES RECORDED IN SEDIMENTS

The sediment record, as revealed in sediment cores, has been used by many investigators to reconstruct the history of contaminant input to aquatic environments (Valette-Silver, 1993). The basic assumptions are that contaminant inputs equilibrate relatively rapidly with sediment inputs (most toxic metals, synthetic organic compounds and PAHs are readily adsorbed onto particles) and that the sediment column studied represents a continuous (i.e. undisturbed) sequence of sedimentation and associated contaminant accumulation.

Establishing the time stratigraphy of cores presents the greatest difficulty in the use of sediments for the evaluation of contaminant histories. In some cases, it is possible to visually count sediment layers. For example, Young et al. (1974) were able to count varves in sediments from the Santa Barbara basin to establish the history of mercury inputs. More recently, radiometric techniques have been used to establish time stratigraphies in cores. In particular, the ^{210}Pb method has provided one of the most useful tools for this purpose. This method was

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developed by Koide et al. (1972) and has been applied in both marine and freshwater environments by Chow et al. (1973), Bruland et al. (1975), Robbins and Edgington (1975), Matsumoto and Wong (1977), Goldberg et al. (1977), Goldberg et al. (1978), Trefry et al. (1985), Kuehl et al. (1986), Alexander et al. (1991a,b) and many others.

The ^{210}Pb method depends on the separation of this isotope in the natural ^{238}U decay series from its effective parent ^{222}Rn and isolation in sediment. Assuming it is unsupported by its parent, the activity of ^{210}Pb decreases by radioactive decay with a half-life of 22.3 years. Corrections for supported ^{210}Pb can be made by determining the ^{226}Ra activity.

With radiochemical chronologies, it is possible theoretically to date sediments over a period corresponding to about five half-lives (~ 100 years for ^{210}Pb) depending on surface activity. One potential problem is that the activity of the radioisotope in surface sediments is assumed constant but will vary with significant changes in grain size. However, such changes are obvious in x-radiographs and thus do not go unrecognized. The measurement of ^{137}Cs provides an independent evaluation of accumulation rates (Olsen et al. 1984) because ^{137}Cs, with a pulsed input centered on 1963 due to atmospheric weapons testing, provide a time-stratigraphic marker.

One problem confronting investigators that are studying contaminant histories recorded in sediments in processes that affect natural sedimentary deposits (thus altering the histories of the deposits). For example, episodes of erosion may obliterate sedimentary layers, a situation which is equivalent to removing pages of history. In addition, bioturbation of the upper layers of deposits smear records so that temporal resolution of the contaminant history is reduced.

Ideally, anaerobic sediments are the best choice for studies of histories of contamination since bioturbation does not smear the time stratigraphy of cores by mixing or homogenizing several years of contamination. Unfortunately, in most shallow coastal areas, aerobic sediments prevail. Because of this, most estuarine sedimentary deposits will have an upper mixed layer. The thickness of this layer in relation to the accumulation rate of the deposit will determine the time-stratigraphic resolution that can be obtained from analyses of cores.

In the present study we analyzed cores from three different sites in the Savannah Estuary (Fig. 1). The first sites (Cores C and E) were subtidal, collected from tributaries of the Savannah River. Similar sites were cored by Goldberg et al. (1979) in their study of metal history in the Savannah Estuary. The second coring sites (Cores F and G) were from intertidal salt marshes. Storti (1980) showed that cores from Georgia salt marshes preserved a trace metal history. The third site (Core H) was from an abandoned boat slip in the Savannah Harbor. Additionally, cores were analyzed from an older site (Core L > 173 years old) and from a site (Core M) north of the Savannah River whose sediments are not derived from the Savannah Estuary.

Sediments accumulating in this depositional environment may be anaerobic, since the cores for these sites have black, sulfide-rich sediments. This, coupled with their relatively rapid accumulation rates, makes them favorable sites for the collection of cores for the purpose of establishing contamination history (Alexander, unpubl. data; Chen, 1993). It seems likely that the different sites might have different pollution histories which would be reflected in their cores.

1.3   TRACE METALS

The interpretation of trace element contamination histories in sediments requires an understanding of some basic geochemical processes in addition to sediment dynamics. Trace elements naturally accumulate in estuarine sediments, associated with the debris resulting from continental weathering. In depositional sites where the natural trace element input is relatively constant, changes in total trace element concentrations reflect contamination. Finney and Huh (1989) used trace element concentrations in sediments of the Southern California Bight deposited during ca. 1845 to normalize concentrations in sediments accumulated more recently. Using this approach, they were able to deconvolve a contamination history for Pb, Zn, and Cr that indicated increasing anthropogenic inputs from about 1900 to 1970 with inputs decreasing thereafter.

For more heterogeneous sediments where the natural trace element input varies, other approaches to interpretation of contamination histories must be used. Goldberg et al. (1969) used aluminum concentrations in sediments of the element-bearing phases in these sediments (i.e. aluminosilicates). Recently, we have demonstrated that the use of aluminum concentrations as a normalizer for downcore trace element concentrations can account for textural inhomogeneities and facilitate interpretation of contamination histories (Windom et al., 1989).

1.4   POLYCYCLIC AROMATIC HYDROCARBONS

As for metals, sediments record the history of hydrocarbon contamination of aquatic environments. A detailed documentation of the increased concentrations of petroleum hydrocarbons due to increased anthropogenic inputs was reported by Wakeham and Carpenter (1976) for dated cores from Lake Washington in urban Seattle. There was a strong correspondence between the growth of the city and sediment hydrocarbon concentrations. Sediments deposited prior to the settlement of the region (ca. 1850) contain only low levels (~20 ug/g dw). Wakeham (1977) subsequently derived a hydrocarbon budget for Lake Washington which showed that storm water runoff contributed about 50% of the annual flux of hydrocarbons to Lake Washington. A number of more recent papers report similar historical trends for various other regions (e.g., Boehm and Quinn, 1978; Wade and Quinn, 1979; Giger et al., 1980; Barrick et al., 1980; Venkatesan et al., 1980).

Historical increases in PAH contamination of sediments have also been reported by a number of workers (e.g. Grimmer and Böhnke, 1975; Müller et al., 1977; Wakeham et al., 1980a,

b; Prahl and Carpenter, 1983; Bates et al., 1984). The most detailed work was initially conducted in lakes. In sediments deposited before the industrial revolution, PAH concentrations are 1-5 µg/g (most are actually derived from biogenic precursors, for example perylene [Wakeham et al., 1980b]). Concentrations in the most recent sediments range between 50-100 µg/g, and again the increased concentrations with time correspond with urbanization and industrialization in the lakes' drainage basins, with the major inputs being urban runoff and atmospheric deposition. In a few cases, PAH concentrations have been decreasing over the past decade (e.g. Wakeham et al., 1980a; Bates et al., 1984), most likely in response to pollution abatement programs. For example, concentrations of PAH in Puget Sound sediments peaked at 30µg/g during the 1940s and 1950s compared to a few µg/g in pre-industrial sediments and 10µg/g at about 1980. Analysis of a dated sediment core from Tokyo Bay showed an increase in PAH from the 1950s to the beginning of the 1970s followed by a decrease to 1982 (Ohta et al., 1983). The increase was ascribed to a rise in the consumption of coal and fuel oils. The decrease observed after 1970 was ascribed to air pollution laws enacted in Japan after 1968. As a result of these laws, there was a marked reduction of air particulate concentration after 1970 in Tokyo. These particulates were assumed to be the major source of PAHs. Many dated cores from North America show a peak in PAH concentrations in the 1950s (Gschwend and Hites, 1981; Zhang et al., 1993).

In one study using dated cores from a Swiss lake it was found that there was a strong, positive correlation between the metals Pb, Hg, Cd, and Zn, and the concentrations of polycyclic aromatic hydrocarbons (Müller et al., 1977). The assumption was made that these pollutants had a common source, such as the burning of coal or other fossil fuels. The use of petroleum has increased exponentially since about 1885 until the 1970s (Wade and Quinn, 1979). Thus, some dated cores in Green Bay showed a peak for PAH concentrations in the 1985 layer, presumably derived from petroleum combustion (Zhang et al., 1993).

1.5   PCBs AND PESTICIDES

Polychlorinated biphenyls (PCBs) are a class of synthetically produced chlorinate aromatic hydrocarbons which are persistent and toxic. Their low water solubility causes them to bind strongly to particles. As a consequence, these compounds tend to accumulate in bottom sediments near urban areas. PCBs were produced commercially in the United States from 1929 to 1976 with peak periods of use from 1965 to 1970. Production was banned in 1976, but use continues until the present time in electrical transformers. However, electrical transformers manufactured after 1976 do not contain PCBs.

Major sources of PCBs in sediments near urban areas include municipal waste waters and aerial fallout (Mearns et al., 1991). Hom et al. (1974) analyzed PCBs from a dated core taken from ocean sediments off southern California and found that PCBs were below detection limits (0.02µg/g) before 1945 and rose to 0.05 µg/g in 1952 and to .103 µg/g in 1967. It is assumed

after the banning of PCB use in the United States that aerial input accounts for most PCBs found in the recent sediments in the United States.

Previous work on dated cores have shown that the concentrations of tri- and tetrachlorobipheyls were reduced in the lower portions of cores while octa- and decabiphenyls increased in the deeper parts of cores. The explanation was that lower chlorinated compounds were eliminated over time by higher mobility and other types of removal processes (Oliver et al., 1989).

In a dated core from a Japanese lake, the concentration of various PCB congeners increased from 1949 to 1959, reached their highest concentration during the 1969 to 1979 period, and declined from 1979 to 1990 (Suguira, 1992). This would correlate with peak use of PCBs in Japan. North American dated cores often show PCBs peaks in the late 1960s (Bopp et al., 1993).

Dichlorodipenyltrichloroethance (DDT) was not identified as a potent insecticide until 1940. The EPA suspended manufacture for general application of DDT in 1972. DDT was widely used in the 1950s and 1960s, with a peak in 1959 for use in the United States. A dated core from Jamaica Bay, New York, showed a peak in the concentration of 4, 4'-DDD in the late 1960s and a decrease since that period (Bopp et al., 1993). A dated core taken from sediments off southern California showed decreases in DDT concentrations between 1971 and 1981 (Stull et al., 1986).

Chlordane was important for termite control during the past 30 years and was widely employed to control grasshoppers and cotton pests. Chlordane was first synthesized in 1944. The EPA canceled all uses of chlordane with the exception of subterranean termite control and on non-food plants in 1974. In 1988 the EPA issued an order banning sales, distribution and use of chlordane. The term "chlordane", as used for pesticide treatment, usually refers to "technical chlordane", a complex mixture of more than 45 individual isomers and congeners. Important compounds include trans-chlordane, cis-chlordane, nonachlor (trans- and cis-), and heptachlor. Work by Kawano et al. (1988) showed that chlordane is a global contaminant. Chlordane concentrations in a dated core from Jamaica Bay, New York, peaked in the 1960s and decreased from that time to the 1980s (Bopp et al., 1993). Shigenaka (1990) has reviewed the status and history of chlordane contamination in sediments throughout the United States.

Dieldrin (1, 2, 3, 4, 10, 10a-hexachloro-6, 7, -poxy-1, 4, 4a, 5, 6, 7, 8, 8a-octahydor-1, 4-endo-exo-5, 8-dimethanonaphthalene) also belongs to the organochlorine pesticides called cyclodienes, characterized by two carbon double bonds. Dieldrin is extremely stable and is one of the most persistent insecticides known. Both aldrin and dieldrin have not been produced in the United States since the mid-1970s, however substantial amounts were imported into the United States until 1984 when the EPA suspended all remaining dieldrin uses.

A NOAA summary paper (O'Connor, 1990) points out that for some pesticides and PCBs, there has been a decrease in concentration since the late 1970s (Crecelius and Bloom, 1988; Eganhouse and Kaplan, 1988).

1.6   TBT

Tributylin (TBT) was widely used in the U.S. during the 1970s and 1980s in marine coatings as a biocide to prevent the growth of fouling organisms. In 1988, regulations were passed in the U.S. to restrict the use of TBT antifouling coating to large craft (more than 25 m) and to remove TBT from retail sales. Butyltin compounds are also used as stabilizers in plastics and as wood preservatives, and polyvinylchloride has been shown to leach dibutyltin into water (Boettner et al., 1982). Thus, we would expect TBT to show increasing concentrations from 1960 to 1988. The waters of some marinas in the U.S. have shown significant decreases in TBT concentrations during the past four years (Seligman, unpubl. data). A complicating factor in understanding TBT in the sediment is the fact that there are two possible sources for the TBT. One is TBT which leaches from boat hulls, adsorbs to suspended particulates, and enters the sediment on particles. A second source of TBT in sediment is associated with paint chips. TBT associated with paint chips may have a very long lifetime, whereas we have found that free TBT is quickly degraded in fine-grained sediment by a clay catalyzed reaction (Stang et al., 1992).

Analysis of dated cores from a marina in France showed higher concentrations of TBT in the top layer (1989-1991) than the subsurface layer (1980-1988) even though TBT was more widely used in the 1980-1988 period (Sarradin et al., 1994). The conclusion was that TBT was degraded in the sediment with a half-life of 2 years. As noted earlier, our own studies have shown rapid TBT degradation in fine grained sediments (Stang et al., 1992).

2. METHODOLOGY

2.1   FIELD SAMPLING

The coring sites represent three different depositional environments: salt marshes, channel bottom sediments and abandoned boat slips. These sites provide sediment histories with annual to decadal time resolutions. Sites with lower accumulation rates, such as some marsh and bottom sediment sites, provide us the opportunity to penetrate sediment records spanning 100-200 years. Sites where sediment accumulation rates are more rapid, such as abandoned boat slips and rapidly accumulating marsh areas, allow us to read the sediment record with greater resolution.

Sediments from salt-marsh and abandoned-slip sites were collected with a variety of coring devices. To preserve the fine-scale resolution contained within these semi-consolidated, rapidly accreting deposits, the upper 50-centimeters of these deposits was sampled manually with pushcores constructed of open-barrel PVC pipe (15-cm ID, 50-cm long). Because of the large

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ratio of cross sectional area to wall-thickness, these types of cores do not disturb the upper portion of the sediment and typically compact the sediments less than a centimeter in a 50 cm core. Sample collection from horizons deeper than 50-cm in the boat slip deposits was not practical with the large-volume sampler and were collected with a vibracorer (core tube 7.5 cm ID, 7-m long) that has been used successfully to retrieve continuous sequences to depths of 7 meters. Cores from subtidal channels were collected with a single-spade box corer (20 x 30 cm cross section, maximum 60 cm long), deployed from the UNOLS vessel RV BLUE FIN. This box corer consistently retrieves the sediment water interface with a minimum of core disturbance. Samples for radiochemical analyses (1 cm in vertical thickness) were removed from push cores and box cores at 1cm intervals to generate complete radiochemical profiles and contamination histories. Samples from vibracores were collected at intervals appropriate for high-resolution sediment analysis, based on knowledge of the accumulation rates within the boat slip from a core collected previously (1-cm intervals in the upper 50 cm, 5-cm intervals in the depth range 50-200 cm, and 10-cm intervals below 200 cms). The outer layer of sediment in each sampling interval, which may be contaminated in the coring process, was removed before samples for analysis were collected. X-radiographs were produced from each core using Kodak Industrex AA X-ray film and a portable KRAMEX X-ray machine. Slabs for X-radiography from pushcores and box cores (2.5 cm thick, 12 cm wide) were collected in plexiglas subsampling trays.

2.2   GEOCHRONOLOGY

X-radiography was used initially to evaluate the extent of bioturbation in each core and allowed us to identify areas where bioturbation or physical disturbance has not affected significantly profiles of radionuclides and pollutants. X-radiographs also allowed us to perceive any artifacts associated with coring operations. Sediment accumulation rates were determined by ^{210}Pb geochronologies which integrate sediment accumulation on 100-y timescales. Rates were verified using ^{137}Cs as a second radiotracer. Activities of radiotracers within each sample were determined concurrently using 2 low-background, planar intrinsic germanium detectors, computer-based MCAs, and custom analysis software.

Accumulation rates were calculated by producing profiles of excess (total minus supported) ^{210}Pb activity with depth in the seabed. Total ^{210}Pb activity was directly determined by gamma spectroscopic measurement of its 46.5 KeV gamma peak in dried, homogenized sediment (Cushall et al., 1983). Supported levels of ^{210}Pb from the decay of ^{226}Ra were determined for each depth interval by concurrently measuring the gamma activity of ^{214}Pb and ^{214}Bi, the short-lived granddaughters of ^{226}Ra. Calculated ^{210}Pb accumulation rates can often be verified using ^{137}Cs as a complementary radiotracer. ^{137}Cs activities were determined directly by gamma spectroscopic measurement of its 662 KeV gamma peak in dry, homogenized sediment (Kuehl et al., 1986; Alexander et al., 1991). ^{137}Cs (half-life 30.0 y) is an impulse tracer (produced from atmospheric nuclear tests), which was first introduced into the environment in significant amounts about 40 years ago. In areas of no bioturbation, the peak of atmospheric weapons testing is preserved as a maximum in ^{137}Cs profiles corresponding to 1963 and provides

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an independent estimate of the sediment accumulation rate. Two short-lived radionuclides, ^{234}Th (half-life 24 d) and ^{7}Be (half-life 53.3 d) were also examined in an attempt to estimate biological mixing rates. Biological mixing rates for the upper sediment column can be calculated from profiles of excess activity of either of these isotopes with depth in the seabed by solving the 1-D advection-diffusion equation, if one assumes that mixing can be modeled as a diffusive process (Krishnaswami et al., 1980; Nittrouer et al., 1983/1984; DeMaster et al., 1985). Gamma activity of ^{234}Th (at 63.3-KeV) and ^{7}Be (at 477.7-KeV) were determined concurrently with the radioisotopes ^{210}Pb, ^{137}Cs, ^{214}Pb, and ^{214}Bi in dry, powered sediment using low-background, planar germanium detectors (Larsen and Cutshall, 1981; Cutshall et al., 1983; Buesseler et al., 1992).

Sediment accumulation rates were calculated using the constant flux (also known as the constant rate of supply) geochemical model (Krishnaswami et al., 1971; Koide et al., 1972; Robbins, 1978; Nittrouer et al., 1979; Kuehl et al., 1986; Alexander et al., 1991 a,b). This model is applicable in areas where the flux of excess ^{210}Pb (unsupported by the decay of ^{226}Ra) and dry-mass sedimentation rate at the seabed have remained constant. This assumption has been shown to be reasonable in areas where the supply of ^{210}Pb is dominated by atmospheric sources (i.e., in marine and estuarine environments; see references above). Radiochemical analyses disclosed the fact that most of the cores (50-cm length and vibracores) did not reach background (i.e., supported) levels of ^{210}Pb. Without complete information on the distribution of excess and supported ^{210}Pb within the sediment column, ages within the column cannot be accurately calculated by the constant flux geochemical model. However, accumulation rates can still be calculated and can be used to derive sediment horizon ages. Dry mass accumulation rates, in g/cm^2, were calculated for each core. Combining the dry mass accumulation rate for each core with the depth distribution of cumulative dry mass, ages were calculated and assigned to depth intervals within each core.

2.3   CHEMICAL ANALYSES

Standard procedures were used to determine the concentrations of metals and organics in the sediment cores. These procedures are described in the enclosed Quality Assurance Plan used for this study (Appendix I).

The procedures for trace metals using inductively coupled plasma-mass spectrometry are given on pp. 10-11 of the QA Plan. Historical values for metals in a NIST standard are given in Table 4 of Appendix I. Procedures for the analysis of pesticides and polychlorinated biphenyls using high resolution fused silica capillary gas chromatography with electron capture detection are given on pp. 12 of the QA plan, with historical values for a NIST standard given in Table 6 of Appendix I. Procedures for the analysis of polycyclic aromatic hydrocarbons by gas chromatography-mass spectrometry using deuterated standards are given on pp. 11-12 of the QA plan. Historical values for PAHs in IAEA standards are given in TABLE 7 of Appendix II. Procedures for the analysis of butyltins are given on p. 13. Procedures for the analysis of total

carbon and nitrogen in sediment using an elemental analyzer are given on p. 11. A gravimetric procedure for carbonate using acid treatment is given on p. 11.

3. RESULTS

3.1   SEDIMENT AGE DETERMINATIONS

A total of thirteen cores were collected in the Savannah River Estuary over the duration of this project. These cores represent the major subenvironments in the estuary (i.e., subtidal channels, vegetated salt-marshes, and abandoned boat slips), each of which may preserve the record of contaminant input differently. We attempted to collect subtidal and intertidal cores from all parts of the estuary and had planned to collect samples from the Back River as indicative of the upper and middle reaches of the estuary. Unfortunately, just prior to the awarding of this grant, the U.S. Army Corps of Engineers, as part of a habitat restoration project, placed an earthen work dam across the Back River, thereby denying access of the area to all vessels. The lack of natural salt marshes and undisturbed sediments in the middle and upper reaches of the main channel of the Savannah River estuary therefore dictated that most of the cores came from the lower estuary.

^{234}Th and ^{7}Be analyses were conducted on the upper 10 cm of cores C, E, F and G. ^{234}Th (half-life 24 days) is produced in the water column from the decay of its parent, ^{238}U, and is rapidly scavenged onto particles. The major source of ^{238}U is seawater; the fresh water content of ^{238}U is very low. ^{7}Be (half-life 53.3 days) is produced in the atmosphere by cosmic-ray spallation of nitrogen and oxygen and reaches the surface of the earth through wet and dry precipitation. The ^{234}Th results were problematic; no trends in activity or structure in the profiles were observed.
Because the source of ^{234}Th is seawater, these results probably indicate that variations in seawater content, as evidenced by salinity fluctuations common in the estuary, produces a variable input of ^{234}Th to the sediment surface. ^{7}Be was observed to be present in only one core (Core C, see below). In most cases, there was a discrepancy between the calculated accumulation rate and the predicted depth of the ^{137}Cs peak from that rate, probably indicating the increased mobility of ^{137}Cs relative to ^{210}Pb within the sediment column.

The radionuclide data are given in Appendix II.

Core A
A subtidal box core collected from South Channel near the southeastern end of Bird Island. This core was composed of well-laminated, over-consolidated muds with thin sand laminae, suggesting very old deposits. Preliminary radiochemical examination of this core revealed very low excess ^{210}Pb in the upper centimeter and none below this horizon, verifying that sediments in this core were greater than about 120 years old. Excess activity of any radionuclide decays to levels below detection limits within about 5 half-lives. Because ^{210}Pb has

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a 22.3 year half-life, sediments with no excess ^{210}Pb can be assumed to be older than approximately 5 half-lives, or 115 years. Surface sediments typically contain some excess ^{210}Pb even if sediment accumulation is very slow because organisms mix ephemerally deposited material that contains some excess ^{210}Pb into the surficial sediment layer.

Core B

A subtidal box core collected from South Channel was composed of sands with minor mud interbeds. This core was not analyzed further because sands are not suitable for use with dating techniques that use radionuclides adsorbed onto particle surfaces. Large particles have a very low surface area to volume ratio, thus limiting the amount of radionuclide that can be adsorbed onto each particle. Nittrouer (1978) and Alexander (unpublished data) show that 80-90% of the activity within a given sedimentary deposit resides on the finer-grained silt and clay particles.

Core C

A subtidal box core collected from a deep hole (-30 feet below MLLW) in South Channel. This core consisted of black, high-water content muds with sand laminae. The fine-grained nature of the core and the well-laminated sedimentary structure observed in x-radiographs indicate that the sediments are relatively undisturbed by biological mixing and should be suitable for detailed analysis.

Profiles of ^{210}Pb, ^{226}Ra and ^{137}Cs all exhibit a cyclic pattern over the length of the core (Figs. 2,3). Each cycle is contained within a sediment layer 7-9 cm thick. The highest activities within each cycle are roughly equal to surficial activities, indicating that all sediments retrieved in this core were "recently" deposited (on a time scale of years). Based on the elemental aluminum concentrations, which are a good proxy of clay mineral content and thus the amount of fine-grained material, these cycles result from activity variations caused by changes in grain size (see discussion for Core B). The mechanism forming these cycles seems to be annual in nature and is probably related to annual floods of the Savannah River. ^{7}Be is observed down to 6 cm within this core, supporting the conclusion that the layers represent annual processes. If an 8 cm average thickness equals 365 days of accumulation (1 year), then ^{7}Be, with its 53 d half-life, should be observed within sediments representing 5 half-lifes (5 x 53 = 266 d), or down to 5.8 cm.

Core D

A subtidal box core collected from South Channel, composed of medium sand. No further analyses were carried out as in Core B.

Core E

A subtidal box core collected from a rarely used, alternative route of the intercoastal waterway, just south of South Channel. This core was composed of muddy sediment which is interrupted by a ray feeding pit. This feeding pit is a shallow, bowl-shaped depression which has

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a cylindrical shaft that extends down into the sediment column to a depth of 30 centimeters. The feeding pit is filled with iron-stained medium sands within the finer grained matrix. Above this sandy fill and up to the sediment-water interface is a well-laminated muddy layer (~15 cm thick) which sits unconformably on the sand layer. The generally fine-grained nature of this core makes it suitable for detailed analysis; the grain-size variations in the core caused by the presence of the feeding structure are corrected for in subsequent analysis of the radiochemical data.

The calculated ^{210}Pb accumulation rates for vertical accretion and dry mass accumulation in this core are 0.56 cm/y and 0.24 g/cm^{2}y, respectively (Figs. 4,5). These accumulation rates were not calculated from the raw activity data as were the other accumulation rates in this study. Because of significant grain size variations (described above), the activity values were normalized to a constant proportion of fine-grained material using the elemental aluminum data for the core. The accumulation rate was then calculated from the decay of excess ^{210}Pb below the rapidly deposited surface layer. The ^{137}Cs profile displays a complex variability with a surficial and subsurface peak of equal magnitude (Fig. 6). Below 20 cm, there is no ^{137}Cs detected, supporting the validity of the calculated ^{210}Pb accumulation rate. Given the accumulation rate, and the timing of first ^{137}Cs input to the environment, ^{137}Cs should not be observed below 22.4 cm.

Core F

A vegetated intertidal push core collected in the back-levee Spartina marsh on western Bird Island. X-radiographs display a homogeneous texture dominated by roots and rhizomes, with few crab burrows. The core was fine-grained throughout and contained a large amount of plant material.

The calculated ^{210}Pb accumulation rates for vertical accretion and dry mass accumulation in this core are 0.83 cm/y and 0.30 g/cm^2 y, respectively (Figs. 7,8). Conditions seem to have been relatively constant over the period of accumulation. ^{137}Cs exhibits a well-preserved subsurface peak at 9.5 cm (Fig. 9). There is poor agreement between the observed depth of the Cs peak and the predicted depth based on the calculated ^{210}Pb accumulation rate, indicating migration of ^{137}Cs within the sediment column.

Core G

A vegetated intertidal push core collected in the back levee spartina marsh on the central portion of Bird Island. X-radiographs display a homogeneous texture dominated by roots and rhizomes, with few crab burrows. However, the rhizome masses that are typically observed in salt marsh cores to be just below the sediment surface were buried beneath approximately 10 cm of mud, indicating a rapid recent input of sediment.

The overall calculated ^{210}Pb accumulation rates for vertical accretion and dry mass accumulation in this core are 0.70 cm/y and 0.32 g/cm^2 y, respectively (Figs. 10,11). However, the profiles of activity vs. depth or cumulative dry mass can be divided into three segments. The

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uppermost segment has high vertical accretion and dry mass accumulation rates of 3.8 cm/y and 1.16 g/cm^2 y. These rates correspond to the upper 10-cm layer of rapidly deposited sediment described above. The zones below the upper zone correspond to times when accumulation rates were lower (see Figures 10 and 12), perhaps during the transition from subtidal and non-vegetated intertidal to vegetated intertidal (Chen, 1993). ^{137}Cs exhibits a well-preserved subsurface peak at 15 cm. There is poor agreement between the observed depth of the Cs peak and the predicted depth based on the calculated ^{210}Pb accumulation rate, indicating migration of ^{137}Cs within the sediment column.

Cores H, I, J

Vibracores collected from an abandoned boat slip across the river from the city of Savannah. Three vibracores, all composed of fine-grained sediments, were taken at the site. The upper 50-cm of the sediment column at each of these coring locations was sampled with the large-diameter push core (see Methods). The best core based on compaction and coring disturbance criteria, Core H, was analyzed in detail.

As in Core G, Core H exhibits several zones between which the accumulation rate has changed. This change in rate was brought about at this coring site because the accumulation characteristics of the boat-slip environment rapidly changed from a subtidal to a non-vegetated intertidal to a vegetated intertidal environment (Chen, 1993). The calculated ^{210}Pb accumulation rates for vertical accretion and dry mass accumulation in the three zones within this core are 2.3, 4.5, and 20.9 cm/y and 0.71, 2.38, and 12.23 g/cm ^{2}y, respectively (Figs. 13, 14). Core H was the only Cs profile that agreed with the predicted depth of the ^{137}Cs peak from the calculated ^{210}Pb rate (Fig. 15). Within the sampling interval, the predicted depth (87.5 cm) and the observed depth (85-90 cm interval) agree perfectly. The predicted penetration depth (117 cm) also agrees perfectly with the observed penetration depth (115-120 cm interval). The rapid accumulation rates associated with this environment minimize the effect of any post-depositional migration of ^{137}Cs.

Core K

A vegetated intertidal push core collected from the freshwater marsh at the uppermost reach of the estuary, above the Houlihan Bridge. X-radiography identified a significant erosional surface in the core; preliminary radiochemical analyses indicated that the depositional record in the core at this site was not complete.

Core L

A pushcore collected beneath the hull of a vessel discovered and excavated by the U.S. Army Corps of Engineers in conjunction with their Savannah Harbor deepening project. The ship has tentatively been identified as one that was damaged by a hurricane in 1820 and was towed into a slough to sink. The ship was subsequently buried under dredge spoil during dredging operations early in the history of the Savannah harbor until being re-excavated in 1993.

Thus cores underneath this hull represent sediment older than 1820 (>173 years old) and provide a good uncontaminated background for our pollutant analyses. Preliminary radiochemical analyses indicate low excess activity in the upper centimeter and no excess below, supporting the idea that these sediments are at least 120 years old.

Core M

A vegetated intertidal push core collected from the leading edge of a marsh that is encroaching onto a very unconsolidated intertidal mud-flat. This site is not located on the Savannah River, but is located just north of the river mouth on the southeastern end of Turtle Island. Sediments supplied to this area may be derived from sources other than those within the Savannah River estuary. High rates of sediment accumulation had been observed previously in this area (Storti, 1980). Preliminary radiochemical analyses indicate that the history of sediment accumulation has been disturbed in this core; thus further radiochemical analyses were not performed. Additional inorganic geochemical analyses were performed to characterize the sediments accumulating in this area, which should be relatively unimpacted by anthropogenic activity within the Savannah Estuary.

3.2 GENERAL SEDIMENT GEOCHEMISTRY

Before the results of chemical analysis of downcore sediments can be interpreted with regard to the pollution history of the Savannah Estuary, the down core chronology of the sediments must be established, as was done in the previous section. The concentration of contaminants can then be compared to time horizons. But before conclusions can be drawn, the concentration of contaminants must also be considered in a proper geochemical context if valid interpretations are to be made. Consideration must be given to the fact that natural processes may lead to downcore variations in chemistry which, if not understood, could be interpreted as due to changes in material input over time.

In assessing downcore sediment chemistry we can expect to see variations due either to steady state or to non-steady state conditions which have occurred over the time period represented by the sedimentary column being studied. Steady state condition implies that depositional rates and composition of various components of the sediment (i.e. organic matter, inorganic phases) have not changed during the time of sediment accumulation, but even under such conditions, post-depositional diagenesis may result in downcore chemical variability. Also implicit in the assumption of steady state is that the sedimentary environment has not changed. Non-steady conditions include changing sedimentary environment, natural variability of the rate and composition of material input to the sediment surface, and changing anthropogenic inputs, which is the signal in downcore chemistry we wish to deconvolve from others. It is particularly important to understand the role that varying conditions play when considering the pollution history of contaminants, such as metals, that also occur naturally.

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In this section we will evaluate some of the general chemistry of the cores selected for study, following the protocols described under "Methodology", that can be used to deduce the relative effects of steady state (digenesis) and non-steady state conditions. For this purpose, major element (i.e. proxies for major sedimentary phases) downcore chemistry provides insight. The relative amounts of silicon, carbon, nitrogen and carbonate in the cores are given in Appendix III, while metal data are presented Appendix IV.

To evaluate downcore metal chemistry for the purpose of detecting enrichments due to anthropogenic activities we must first understand what natural metal concentrations to expect and how they may vary. The dominant natural metal-bearing phase in sediments of southeastern estuarine sediments is aluminosilicates, or clay minerals. Windom et al. (1989) and Hanson et al. (1993) have used aluminum as a proxy for the concentration of aluminosilicate minerals. These workers demonstrated that for natural sediments the concentrations of metal covaried with the concentration of aluminum, thus providing a tool (i.e. using Al) to normalize results of metal analysis of sediments to account for natural and unnatural enrichments. This approach was used to evaluate metal concentrations in sediments from the Savannah Estuary.

Results of downcore aluminum analyses (Figure 16) for the six sediment cores studied indicate some top to bottom variations which clearly must be taken into account in assessing anthropogenic influences on metal enrichment in these sediments. For example, Core H, F, and G have decreasing aluminum concentrations toward the surface. This implies that the total natural metal concentration in these cores should decrease toward the surface as well. Core E has a sharp break in the Al concentration at about 30 cm downcore which suggests a rather abrupt decrease in the delivery of fines to the site location of Core E (Figure 1).

Core C exhibits a cyclic pattern in aluminum concentrations with minima occurring at the surface, 10 cm, 20 cm, 27 cm, 35 cm, and 44 cm depth. This cyclic pattern was also observed in the ^{210}Pb data (previous section) and is observed in other chemical parameters (discussed below), and may represent episodic changes in sediment delivery.

Core M, collected from Turtle Island at a location relatively removed from the direct influence of the Savannah River, has a relatively uniform aluminum concentration suggesting that sediment delivery to this site was fairly constant in terms of the natural component (i.e. fine grained clays), with time.

The distribution of silica in the cores studied can be assessed by use of downcore Si/Al ratios (Figure 17). Since silica associated with aluminosilicates would be accounted for by Al, changes in the ratio must reflect other sources. The abrupt increase in the Si/Al ratio in the upper half of Core E coincides with the abrupt decrease in aluminum (Figure 16) and is clearly the result of more coarse quartz sand input. The Si/Al cyclicity shown in Core C is similarly due to changes in sediment texture associated with increased quartz sand. The increases toward the surface of Si/Al in the other cores (i.e. H, F, G, and M) while aluminum decreases (Figure 16)

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also suggests the increased contribution of quartz sand, although some of the increase in Core M is likely associated with increased biogenic silica input due to changes in diatom production.

The distribution of nutrients in downcore sediments may reflect the effects of both diagenetic processes and changes in the characteristics of the depositional environment. For example, the degradation and remineralization of organic matter subsequent to its deposition in estuarine sediments should be reflected in a downcore decrease in concentrations of nutrients, particularly carbon and nitrogen. Chen (1993), however, found that decreases in nutrients downcore due to these diagenetic processes are limited to the upper 10 to 20 cm in southeastern estuarine sediments. Changes in depositional characteristics, on the other had, may result in variations over greater depths in the sediment column. For example, as a sedimentary environment changes from subtidal to intertidal, a change in the rate and composition of organic matter input may be expected. For southeastern estuarine sediments, Chen (1993) has suggested that as the depositional environment changes from subtidal to intertidal salt marsh, the organic matter sedimentation rate increases. As this change occurs, he found that the composition of the organic matter tends to become dominated by salt marsh grass (*Spartina alterniflora*) detritus rather than diatom detritus.

Of the nutrients deposited in estuarine sediments in association with organic matter, phosphorus is most easily remineralized. This apparently results in a relatively uniform downcore distribution in the phosphorus concentration (Figure 18).

Increase in organic carbon toward the surface of cores H, F, and G (Figure 19) suggest that there has been a change in the rate of organic matter input and the C/N ratio (Figure 20) suggests that the composition of the organic matter (at least in cores H, M, and G) changed toward more refractory material in recent sediments (i.e. higher C/N ratio). This is consistent with the results of Chen (1993) who suggested that intertidal cores record the increased importance of salt marsh detritus input toward the surface. Salt marsh detritus is considerably more refractory than phytoplankton detritus.

It could be argued that the downcore decrease in organic carbon is due to diagenesis (i.e. degradation) of organic matter. Results of the manganese analyses, however, seem to support the changing organic matter input hypothesis. The Mn/Al ratio (Figure 21) indicates less enrichment of manganese with increasing organic carbon (Figure 22). This relationship is also exhibited to a lesser degree in the results of Core G. These results suggest that as organic matter input to the sediment surface occurs, manganese is more efficiently reduced and released back to the water column. All cores still, however, maintain a diagenetic manganese imprint in surface sediments indicated by enrichment in the surface oxidized layer.

An alternative explanation of the decreased manganese in surface sediments may be the decreased efficiency of microbial oxidation of the metals with increasing salinity of sediment pore waters as demonstrated by Spratt and Hodson (1994). As intertidal sediments become more

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elevated (i.e. as sediment accumulates) the period of low tide desiccation increases, presumably leading to increased pore water salinity. This, of course, should then lead to less efficient oxidation of Mn as suggested by Spratt and Hodson (1994). This, however, would not explain the results obtained in subtidal Core-E for carbon and manganese (Figures 19 and 21).

It is likely that the increased concentration of organic carbon toward the surface of Core E is due to increased organic matter input driven by anthropogenic influences (e.g. increased nutrient delivery, sewage discharge, pulp mill effluents, etc.). It is also likely that some of the increased organic matter delivery to the intertidal cores is due to anthropogenic influences. This is supported by the observation of no significant increases in carbon contributions in Core M (Figure 19) which is a core most removed from anthropogenic inputs.

3.3   METAL CONCENTRATIONS

This section presents the results of metal analyses in downcore sediments in the six cores collected from the Savannah Estuary and chosen for study. As was discussed in the previous section, aluminum is used to normalize metal data to account for natural variance, since aluminosilicate minerals represent the major natural metal bearing phases. Data are therefore presented as metal:Al ratios versus depth in the cores. The actual unnormalized data are presented in Appendix IV.

The metal data are presented below, by metal. Based on the depth variations observed in the metal:Al ratios an attempt is made to separate patterns due to anthropogenic inputs from those due to natural processes. Observed anthropogenic patterns will then be assessed temporally in Chapter 4 to deconvolve pollution histories.

Silver (Ag)
Variations in the Ag:Al ratio for Core M (Figure 23) are minimal and are probably due to natural variability and/or to sampling and analytical artifacts, since this core is least likely to be influenced by anthropogenic inputs. With the exception of the surface sample, variations in the Ag:Al ratio of Core C are probably due to similar causes (i.e. natural variability or sampling/analytical artifact). Ag:Al variations in cores H, E, F, and G, however, indicate that silver is enriched above naturally expected concentrations (i.e. in aluminosilicate minerals) in upper layers of sediments from these areas. These enrichments are not easily explained by natural geochemical processes.

Arsenic (As)
With the exception of Core E the downcore variations in As:Al ratio in the cores appear to be relatively random (Figure 24). No patterns suggesting significant anthropogenic enrichment are observed. Arsenic does, however, appear to be enriched toward the surface of the subtidal Core E is considerably more sandy with lower aluminosilicate clay content (as judged

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for the aluminum data shown in Figure 16). Thus small anthropogenic inputs would have a more apparent influence on the As:Al ratio in this core than perhaps the others.

Cadmium (Cd)

Variations in the Cd:Al ratio indicate enrichment toward the surface in Cores H and E (Figure 25). Variations observed in the other cores do not suggest significant enrichment.

Copper (Cu)

In general the Cu:Al ratio in all the cores studies shows no systematic variations that might suggest anthropogenic enrichment (Figure 26). Core-E and Core-F which exhibited the greatest textural and organic carbon variability, respectively, showed the greatest variability in the Cu:Al ratio.

Chromium (Cr)

Based on the Cr:Al ratios (Figure 27), chromium is enriched, relative to expected background values, in upper portions of all cores except Cores C and M. In Cores H, F, and G the Cr:Al ratio goes through a maximum in the upper portion of the cores then declines toward the surfaces.

Iron (Fe)

This metal is not likely to be enriched in sediments due to anthropogenic activities because of its great natural abundance. In fact, most of the variations in the cores studied do not exhibit Fe:Al ratios that would suggest significant enrichment (Figure 28). The significant decrease in the Fe:Al ratio in the upper portion of Core F may reflect the increased reducing characteristics of conditions during the deposition of the upper part of this core, during a period when organic carbon input was significantly increased (Figure 19) as was discussed in the previous section.

Mercury (Hg)

The Hg:Al ratio in sediments from all cores shows little variation with depth with the exception of the upper portion of Core H (Figure 29). This large spike in the Hg:Al ratio is clearly an anthropogenic signal. The smaller maximum in the Hg:Al ratio near the surface of Core F may also be the result of anthropogenic inputs.

Nickel (Ni)

The variations in the Ni:Al ratio in all six cores studied (Figure 30) suggest no anthropogenic influences. The ratio in Core M is observed to decrease systematically from top to bottom with the upper portion depleted in nickel relative to the lower portion (with respect to natural concentration associated with aluminosilicate minerals). This could represent a shift in the dominance of different natural sources of sediment.

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Lead (Pb)

With the exception of Core C, the Pb:Al ratio in all cores either goes through a maximum (Cores H, E, and F) or increases in the upper portion of the core (Figure 31). These features are consistent with an anthropogenic influence. The Pb:Al ratio throughout the lower portion of Core C is relatively high, and goes through a minimum at the surface. It is not clear how to interpret this but these data are discussed further in the next chapter of this report.

Antimony (Sb)

The Sb:Al data (Figure 32) is rather scattered owing to the concentration of antimony being so low (see data in Appendix IV). It is difficult to deduce an anthropogenic signal but based on the Sb:Al profiles antimony does appear to be enriched in Cores H and F near the surface.

Selenium (Se)

Selenium concentrations were extremely low in all samples (see Appendix IV) and no obvious trends in the Se:Al ratio with depth (Figure 33) were observed except the relatively high values in the upper 10 cm of Core M. Cores C and F have Se:Al profiles that also suggest enrichment toward the surface and there is no diagenetic reason for this trend.

Tin (Sn)

Based on the Sn:Al ratio (Figure 34) tin appears to be relatively uniformly distributed in subtidal Core C. The tin distribution in Core M suggests depletion in the upper portion at the core, similar to the nickel distribution, and may represent changing natural sources.

Although the scatter in the Sn:Al data is rather large, results indicate tin enrichment toward the surface of Cores H, E, F, and G (Cores G and H results suggest maxima in the Sn:Al ratio at around 20 cm depth in both cores). These results are consistent with anthropogenic inputs.

Zinc (Zn)

The Zn:Al ratio observed in Core M is constant throughout the length of the core (Figure 35). As stated earlier, the site where this core was collected is most remote from contaminant sources in the Savannah Estuary. The ratio in Cores H, E, F, and G generally increase toward the surface suggesting anthropogenic inputs.

3.4   POLYCYCLIC AROMATIC HYDROCARBONS (PAHs)

In Tables 1 - 3 are the concentrations of each of 22 selected PAHs from various depths in cores E, F, and H and the dates determined for each depth analyzed. "Total PAHs" refers to total concentrations of the 22 selected PAHs. Profiles of total PAH, fluoranthene and perylene concentrations with depth are shown in Figures 36-41. Total PAH concentrations throughout core F were all below 900 ng/g (Figure 38). Core E had low PAH concentrations except at a

depth of 55 - 56 cm (1900) where total PAHs were 4600 ng/g (Figure 36). Highest concentrations of PAH were found in Core H (Figure 40) and within this core the highest concentration of total PAH was 7240 ng/g at a a depth of 130 - 135 cm (dated age 1958). The layer at 150 - 155 (dated age 1954) was 7160 ng/g so it appears that the period from 1954 to 1958 had the highest input of PAHs. A profile of fluoranthene concentration with depth in Core H also showed a peak in concentration at 130 -135 cm (1900 ng/g - Figure 41). Perylene, which is thought to be produced by diagenesis, incrased in concentration at deeper depths going from 43 ng/g at the 195 - 200 cm layer to 812 ng/g at the 465 475 cm layer depth (Figure 41).

3.5   POLYCHLORINATED BIPHENYLS (PCB)

The concentrations of 20 congeners of PCBs in cores E, F, and H at various depths and the dates calculated for these dpeths are given in Tables 4 - 6. The detection limit for each congener is given in Table 7. Profiles of total PCBs with depth and time in Cores E, F and H are given in Figures 42-50. "Total PCBs" are the concentraitons of the 20 congeners selected for analysis at each depth. The major feature of both Core F and H was that the highest concentrations of PCB in both cores were in 1967, 32 and 106 ng/g in Cores H and F respectively (Figures 46 and 49). There was some evidence of non-steady state conditions in Core E and after analysis at a few depths no further work was done on this core (Table 6). Concentrations of PCBs in Core H were barely detectable from 1920 to 1937 with a gradual increase from 1944 rising to a peak of 32 ng/g in 1967 and then remaining between 16 and 22 ng/g since 1967. Core F in the salt marsh showed higher PCB concentration throughout the core than Core H, but the profile was similar to Core H. Most individual congeners also showed highest concentration at depths whose age was calculated to be around 1967 (Tables 4 -5, Figures 47 and 50).

3.6   PESTICIDES

The concentration of the 16 pesticides from Cores F and H are given in Tables 8 and 9. The detection limits for each pesticide are given in Table 10. The detection limits listed are lower than those called for in the Quality Assurance Plan (Appendix I, pp. 6 - 7). The lower detection limits were needed because of the very low concentrations of the pesticides in the cores. The lower detection limits were achieved by concentration of the extracts to small volumes and thus injections of a large percentage of the total purified extract. The depth profiles of selected pesticides (total DDTs, 4,4'-DDE, alpha-chlordane, and dieldrin) are given in Figures 51-56. Total DDT refers to the concentration of all of the isomers (2,4'-DDT, 4,4'-DDT, 2,4'-DDE, 2,4'DDD, 4,4'-DDD) with 4,4'-DDE and 4,4'-DDD being the major isomers. Highest concentrations of dieldrin, total DDT, 4,4'-DDE, and 4,4'-DDD in Core F were found at a depth of 9 - 10 cm, which was dated to 1984. The major pesticides found in Core F were 4,4'-DDE, 4,4'-DDD, and dieldrin. Low concentrations of lindane and alpha-chlordane were found throughout Core F. Heptachlor, heptachlor eposide, aldrin, mirex, trans-nonachlor, endrin, and hexachlorobenzene were non-detectable in Core F (Table 8). The ratio of 4,4'-DDD to 4,4'-DDE ranged from .23 to .60 in Core F. In Core H the highest concentrations of dieldrin, 4,4'-DDE and

4,4'-DDD were in the 1967 layer (11.8 ng/g of 4,4'-DDE, 6.2 ng/g of 4,4'-DDD, and 2.0 ng/g of dieldrin) (Table 9, Figure 54-56). In Core H there was a gradual increase in 2,4'-DDE from 1954 reaching a peak in 1967 and then a decrease from 1967 to recent time (Figures 55-56). Thus, the highest concentrations of DDTs and dieldrin occurred very different times in Core F (1984) and H (1967). It should be noted that the highest PCB concentrations in both Cores F and H were in 1967. In Core H the major pesticides were 4,4'-DDE and dieldrin. Low concentrations of lindane, aldrin, and alpha-chlordane were found throughout Core H with non-detectable amounts of heptachlor, heptachlor eposide, mirex, trans-nonachlor, endrin, and hexachlorobenzene in most sections. The ratio of 4,4'-DDD to 4,4'-DDE in Core H ranged from 0.53 to 1.09 from 1954 to 1967 and then ranged from 0.16 to 0.21 from 1975 to 1988. The approximately one-to-one ratio of DDD to DDE in 1954 suggests a largely anaerobic environment at that period at site H, since DDD is formed from DDT in an anaerobic environment.

3.7   BUTYLTINS

The concentrations of tributyltin, dibutyltin, and monobutyltin in the cores E, F, and H are reported in Tables 11-13. Detectable levels of butyltins were low and only detectable in the top layers of Cores H and E. The concentrations of tributyltin in the surface layer of cores H and E were 7.5 and 8.2 ng/g, respectively. Concentrations of dibutyltin in thr surface layer of Cores H and E were 4.5 and 4.2 ng/g, respectively. Monobutyltin was not detected in the top of Core F or in subsurface layers. Since butyltins were not found below the top layer of any of the three cores, extensive analyses were not carried out on the various deeper layers of the cores.

4. POLLUTION HISTORY

In this chapter we combine the results of downcore sediment dating and contaminant analysis, discussed in the previous chapter, to deconvolve a pollution history of the Savannah Estuary. We then evaluate the pollution histories of contaminant groups, in relation to human activities, in an attempt to identify contaminant sources and their time-varying influences.

4.1   METAL POLLUTION HISTORY

Downcore metal variations, using Al normalized data, were evaluated in Chapter 3 to identify those that could be likely attributed to anthropogenic influences. That evaluation was made on the basis of data for six cores but geochronologies could be established on only four of these: H, E, F, and G. Core C contains only recent sediments (~ 8 years), and metal variations were not generally significant in this core. Core M is useful as a control even though it could not be dated. Thus the pollution histories are established using data from Cores H, E, F, and G.

Based on an overall review of the metal data, four contaminant-time patterns were identified. These patterns exhibit reasonable consistency between cores and appear to be

explainable by human activities. The metal patterns which exhibit the most obvious anthropogenic signals are those for silver, cadmium, zinc, mercury, chromium, and lead.

Silver, Cadmium, and Zinc

In the dated cores, the variations in these metals with time follow similar patterns (Figures 57, 58, and 59). The patterns in Core E for the metals generally show a greater response to anthropogenic influences than observed in the other cores probably due to the relatively smaller contribution of the natural input (Core E was more sandy in its upper half).

The pattern for silver, cadmium, and zinc is characterized by a steady, slow increase toward the present time, with no significant abrupt maxima (the maxima in the Cd/Al peak observed in the late '70s [Figure 59] coincides with a Hg/Al maximum [Figure 63] and will be discussed below). This pattern would appear to be consistent with a steadily increasing non-point source for these metals.

Perhaps the best indicator of an increasing non-point source due to human activity is population growth. The population of Chatham County (Figure 60) would be expected to have the most significant effect on the Savannah estuary and the pattern of increases in silver, cadmium, and zinc. These metals would be clearly associated with increased population; silver is commonly associated with treated municipal wastes, and cadmium and zinc are associated with galvanized pipes and rubber products (e.g. automobile tires). Tin, used in plumbing solder, is another metal that may be increasingly discharged with population growth. The Sn/Al pattern in dated cores (Figure 61), while not as obvious as those for silver, cadmium, and zinc, may also be a result of non-point discharge associated with population growth.

Chromium

The pattern of chromium enrichment is dated cores is characterized by a maximum (Figure 62). Going from Core H, farthest up the estuary, to Core G, near the mouth, the Cr/Al maximum occurs at progressively more recent sediment horizons. Returning to Core H, the Cr/Al rato appeared to rise significantly in the 1950s. This coincides approximately with the initial operation of a titanium dioxide pigment-processing plant. The raw material for this plant is the mineral ilmenite, and waste products from this plant contain significant amounts of chromium. The plant was bought by Kemira Oy in 1985, but prior to this, significant steps were taken in the 1960s to reduce atmosphere emission and effluents. The results of this effort are clearly evident in the data from Core H (Figure 62).

Core H was collected nearest the Kemira plant, which is located on the south side of the river across from the southeastern tip of Hutchinson Island (Figure 1). Cores F and G are located progressively farther away, down the estuary. Thus the chromium enrichment pattern in these cores may reflect a time lag as contaminated sediments move downstream and are redistributed.

<u>Mercury</u>

A pattern of mercury enrichment was only observed in Cores H and F (Figure 63). In Core H a well-defined maximum in the Hg/Al ratio occurs at about 1968. A much less significant maximum occurs in Core F just below the 1990 horizon.

It is difficult to ascribe this very spatially and temporally localized mercury input to the Savannah Estuary to a specific source. Two possibilities, however, are: 1) a chlor-alkali plant that operated in Augusta, Georgia (about 100 miles upriver) during the 1960s and was cited for mercury release during the late sixties, and 2) local companies that also operated during this time. The chlor-alkali plant is probably a poor candidate as a source for the mercury contamination since its influence on the estuary would be expected to be more widely distributed. The Cd/Al maxima, mentioned above, although not well defined, is likely associated with the same source as the mercury enrichment maximum.

<u>Lead</u>

The distribution pattern of lead is not particularly consistent between the four dated cores (Figure 64). A maximum in the Pb/Al ratio is evident in Cores H and E at about the same date horizon, whereas in Cores F and G the enrichment maximum appears to almost intersect the sediment surface.

Lead contamination of the environment is often attributed to the product of alkyl lead compounds for use in gasoline. This lead use rapidly increased in the 1940s and '50s (Figure 65) coinciding reasonably well with the lead enrichment pattern observed in Cores H and E, although the decrease in lead enrichment in these cores appears too early. Cores F and G do not appear to record the leaded gasoline use at all. Thus these results suggest that lead contamination of the Savannah Estuary is likely dominated by another, local source. A local industrial source is likely, with the decrease in the lead enrichment shown in Core H coinciding with increased pollution abatement activities which occurred in the late 1960s and early '70s. The more recent maxima in the lead enrichment observed in down-estuary cores probably reflects the lag in the transport of contaminated particles downstream.

4.2   POLYCYCLIC AROMATIC HYDROCARBON (PAH) HISTORY

Because of the generally low PAH concentrations in Cores E and F, it is difficult to determine trends using total PAHs (Figures 36 and 38). Fluoranthene and pyrene were the predominant anthropogenic PAHs found in the cores and their profiles can be useful in looking at temporal trends. For example, in Core F, fluoranthene and pyrene (Figure 39, Table 1) showed a gradual increase in concentration from a depth of 37 cm (age - 1951) to 9 cm (age - 1984) followed by a decrease from 9 cm to the surface (age - 1992). In Core H the major features were a large increase in PAH concentrations (Fig. 40) from a depth of 175 cm (age - 1948) to 135 cm (age - 1958) followed by a decrease in concentration from 135 cm to the surface (1993). Between 1958 and 1962 there were significantly more input of anthropogenic PAH to site H in the Savannah River estuary than before or after this period.

The increase in anthropogenic PAHs from 1958 to 1962 may have been due to increases in the growth in population and industry of Chatham and other counties surrounding the Savannah Estuary. The decrease in PAHs after 1962, with relatively low concentrations after 1976, may be due to the passage of pollution control laws. Increased concentrations of PAH in the 1950s sediments has been shown in other dated cores. For example, concentrations of PAH in Puget Sound, Washington, peaked at 30 µg/g during the 1950s and decreased to 10 µg/g in 1980 (Wakeham et al., 1980a; Bates et al., 1984). Analysis of a dated sediment core from Tokyo Bay showed an increase in PAH from the 1950s to the beginning of the 1970s followed by a decrease until 1982 (Ohta et al., 1983).

The much higher concentration of PAHs in Core H compared with Core F can probably be explained by the location of the two sites (see Figure 1). Site H is adjacent to the city of Savannah, near oil farms and other industry located on the Savannah River. Sites F and E are further downriver, away from the city and most of the industry associated with the Savannah River. The relatively high PAH concentration at a depth of 55 cm (age - 1900) in Core E (Figure 36) is surprising and possibly due to some unusual input during that period near that site. Perylene, a non-anthropogenic natural hydrocarbon, is produced from sediment lipids by diagenetic processes and, as expected, was found at higher concentrations in the deeper parts of Cores H and F (Figures 39 and 41). In the lower portions of the core the major PAH is perylene and is almost 10 times higher in concentration than anthropogenic hydrocarbons.

4.3 POLYCHLORINATED BIPHENYL HISTORY

PCB concentrations were very low in the 1920 to 1940 section of the dated cores (Figures 46 and 49, Tables 4 and 5). Total PCBs were at their highest concentrations in 1967 in both Cores F and H, 106 and 32 ng/g, respectively. The period from 1965 to 1970 was the peak period for the use of PCB in the United States. Production was banned in 1976, but older electric transformers can still contain PCBs. The sources of PCBs in upper sections of Cores F and H could be leakage from transformers located in the Savannah Estuary, older upland sediments with associated PCBs washed downriver into the Savannah Estuary, and aerial transport. Dated cores in various parts of North America generally show large concentrations of PCBs in the late 1960s layers (Bopp et al., 1993). A dated core from a Japanese lake analyzed for PCBs showed a profile similar to the profile for Core H, namely an increase from 1949 to 1959, highest concentrations during the 1969 to 1979 period and a decline after 1979 (Suguira, 1992). Even the highest concentrations of PCB found in the cores (Core F - 106 ng/g) are relatively low compared with the concentrations found in sediments adjacent to large urban areas. For example, PCB concentrations found in the sediments in the Hudson River, New York, range from 1000 to 24000 ng/g (Bush et al., 1987).

4.4 PESTICIDES HISTORY

The major pesticides found in Cores F and G were two isomers of DDT, namely 4,4'-

DDE and 4,4'-DDD. Next in abundance was dieldrin. Dieldrin has not been produced in the United States since the mid-1970s, however substantial amounts were imported into the United States until 1984 when the EPA suspended all remaining dieldrin uses. DDT was widely used in the 1950s and 1960s with a peak usage in the United States in 1959. The EPA suspended the manufacture of DDT in 1972. Profiles of dieldrin, 4,4'-DDD and 4,4'-DDE were quite similar. In Core H the highest concentrations were at depths of 90-95 cm (age - 1976), while in Core F the peak concentrations for these compounds were at 9-10 cm (age - 1984). The 4,4'-DDE was below detection (<0.56 ng/g) in the 1967 layer of Core F while it was 11.8 ng/g in the 1967 layer of Core H. This suggests that in the late 1960s the application of DDT was widely different in different parts of the Savannah Estuary. One possible explanation would be the use of DDT in the 1960s to control the numerous mosquito breeding ponds on Hutchinson Island, which is the location of site H. It seems likely that Bird Island (location of site F) would not be a site for mosquito control abatement during the 1960s since there are fewer mosquito breeding areas on this island and fewer residential areas are nearby.

A dated core from Jamaica Bay, New York, showed a peak in the concentration of 4,4'-DDD in the late 1960s and a decrease since that period (Bopp et al., 1993).

Several sources could account for the presence of dieldrin and DDT isomers in the upper (more recent) parts of the cores. One is that older sediments (e.g. from the 1960s) from agricultural areas with their associated DDT isomers are still being washed into the Savannah River and transported into the Savannah Estuary. A second source is the aerial transport of DDT isomers and dieldrin from areas where these pesticides are still widely used, which includes many developing countries.

DDT is rapidly converted to DDE or DDD in sediments, thus explaining the lack of DDT in all cores. DDE is a product of DDT under aerobic, oxidizing conditions while DDD is a product of DDT under anaerobic, reducing conditions due to microbial activity aand the reaction of DDT with iron porphyrins (Boul et al., 1994). In Core F, the ratio of 4,4'-DDD to 4,4'-DDE ranged from 0.23 suggesting primariy oxidizing conditions at the time when the DDT first associated with the sediment. In Core H, the ratio ranged 0.53 to 1.0 from 1954 to 1967 and then ranged from 0.16 to 0.21 from 1975 to 1988. This suggests that conditions changed during these two periods, so that in 1954 when DDD and DDE were approximately the same concentration, the conditions of deposition were more reducing than during the later period (1975 to1988).

4.5   HISTORY OF BUTYLTINS

The low concentrations of butyltins in the top layers of Cores, E, F, and H and nondetectable amounts in the subsurface sediments is not surprising based on the information available on butyltins in sediments. High concentrations of tributyltin (TBT) have been found in sediments from shallow marinas and in sections of harbors where there is active shipping and ship repair facilities (Espourteille et al., 1993; Krone et al., 1989; Makkar et al, 1989; Stang et

al., 1992). In areas where there is active circulation of the water the TBT concentrations are often below the limits of detection. For example, TBT was below the detection limits in the Chesapeake Bay (< 1 ng/g; Espourteille et al., 1993). A survey of TBT in coastal areas of the United States showed highly variable TBT concentrations with 25% of the sites having no detectable TBT (< 5 ng/g; Wade et al., 1990). An earlier study showed that sediment from the Skidaway River, which is near the Savannah Esturary, had no detectable TBT (2 ng/g; Stang et al., 1992). Because of the degradation of TBT by biotic and non-biotic processes, the subsurface TBT concentrations are generally much lower than the surface concentraitons. Stang et al. (1992) found that fine-grained sediments were able to catalyze the non-biotic degradation of TBT leading to dibutyltin, monobutyltin and inorganic tin ion in a few days. Analysis of dated cores taken from a marina in France showed higher concentrations of TBT in the surface layer (age - 1989-1991) than the subsurface (1980-1988) even though TBT was more widely used in the 1980-1988 period (Sarradin et al., 1994). They calculated a half-life of two years for TBT in this core. Other studies using dated cores have calcuated half-lives in freshwater and marine sediments of a few months to 2 years (De Mora et al., 1989; Fent et al., 1991; Maguire and Tkacz, 1985). Thus, such degradative processes would account for the lack of butyltins in subsurface sediments of the Savannah Estuary.

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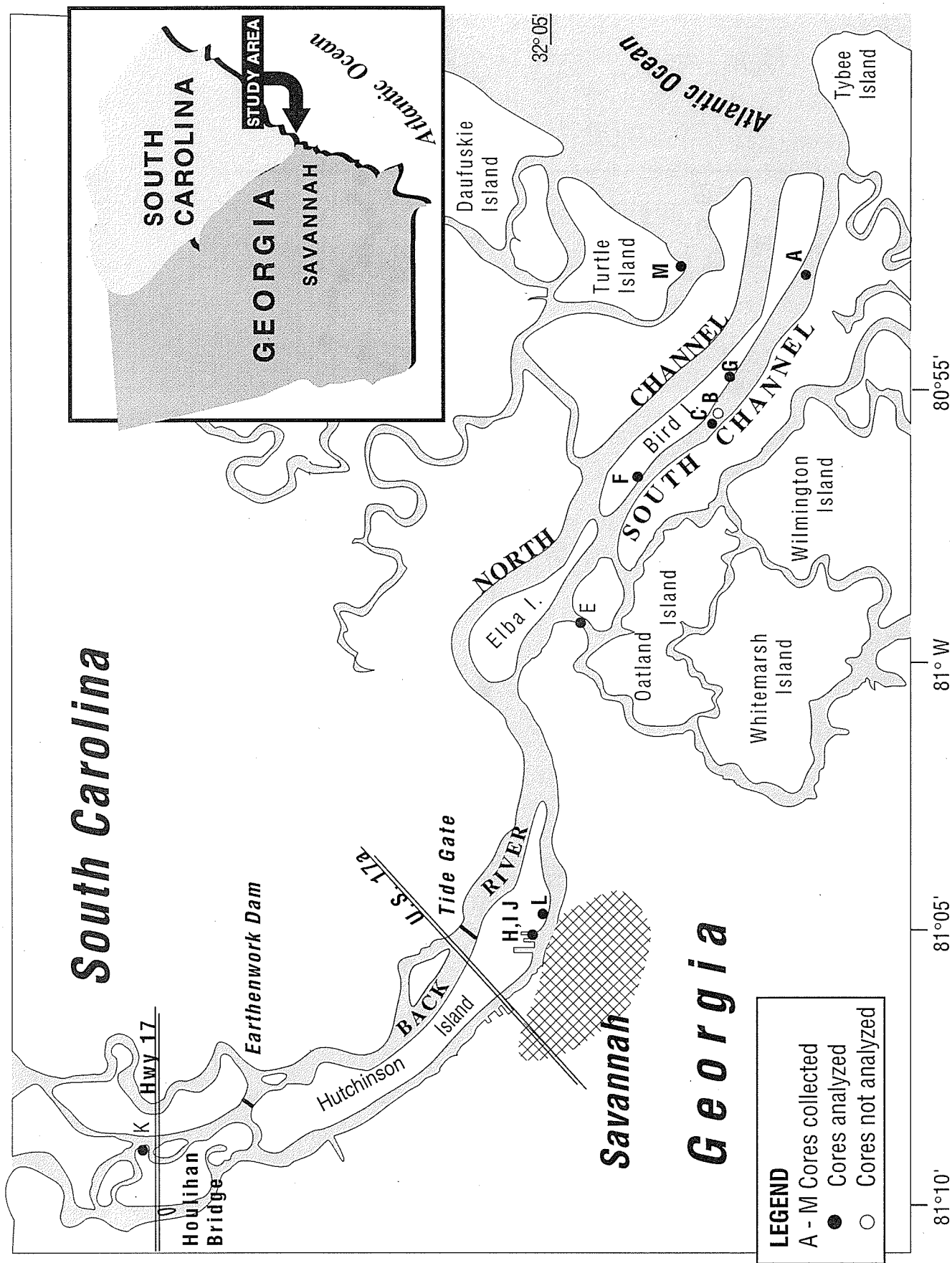
Fig. 1. Map of Study Area
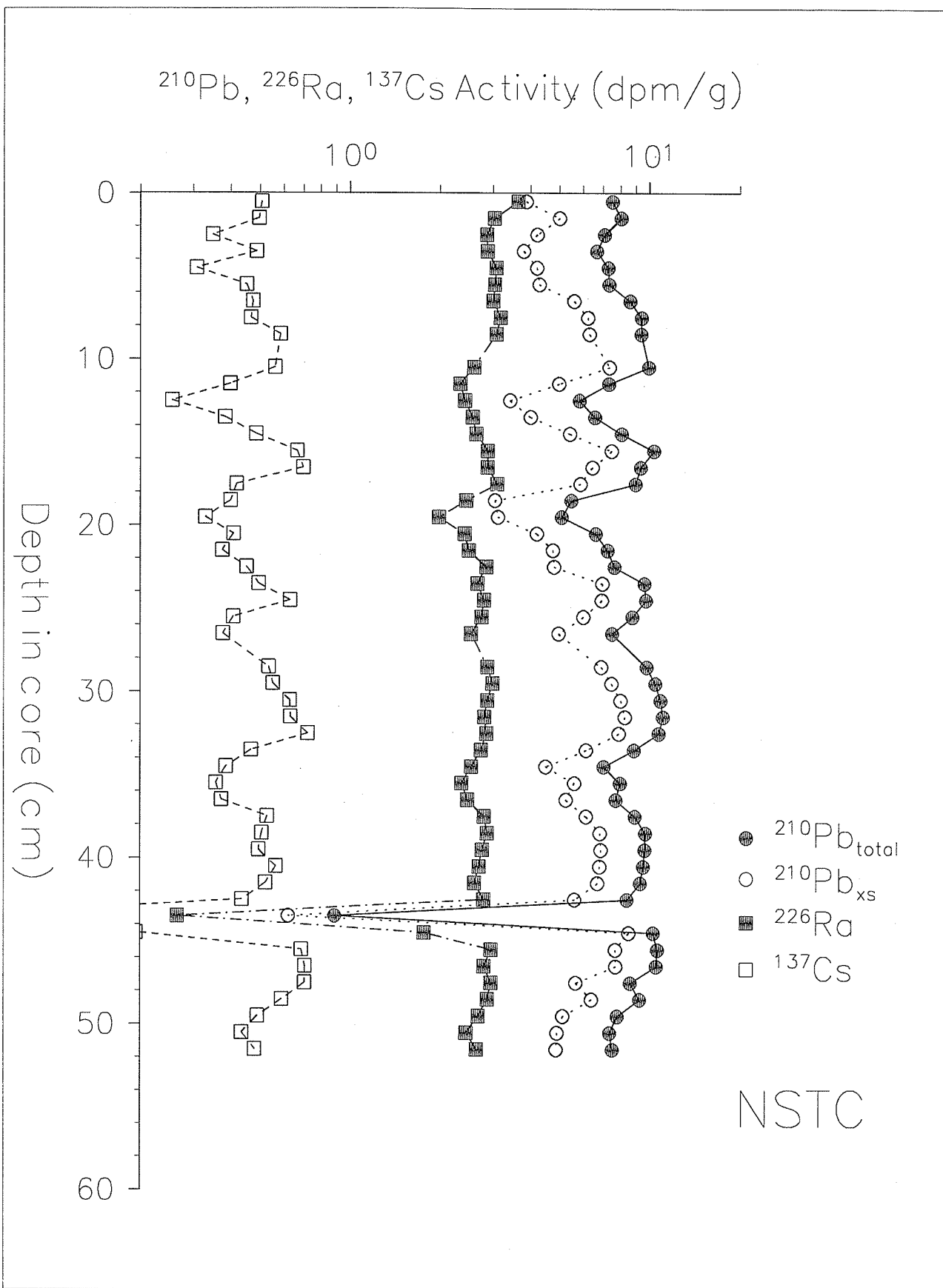
Figure 2. Depth vs. ^{210}Pb, ^{226}Ra, and ^{137}Cs Activity—Core C.
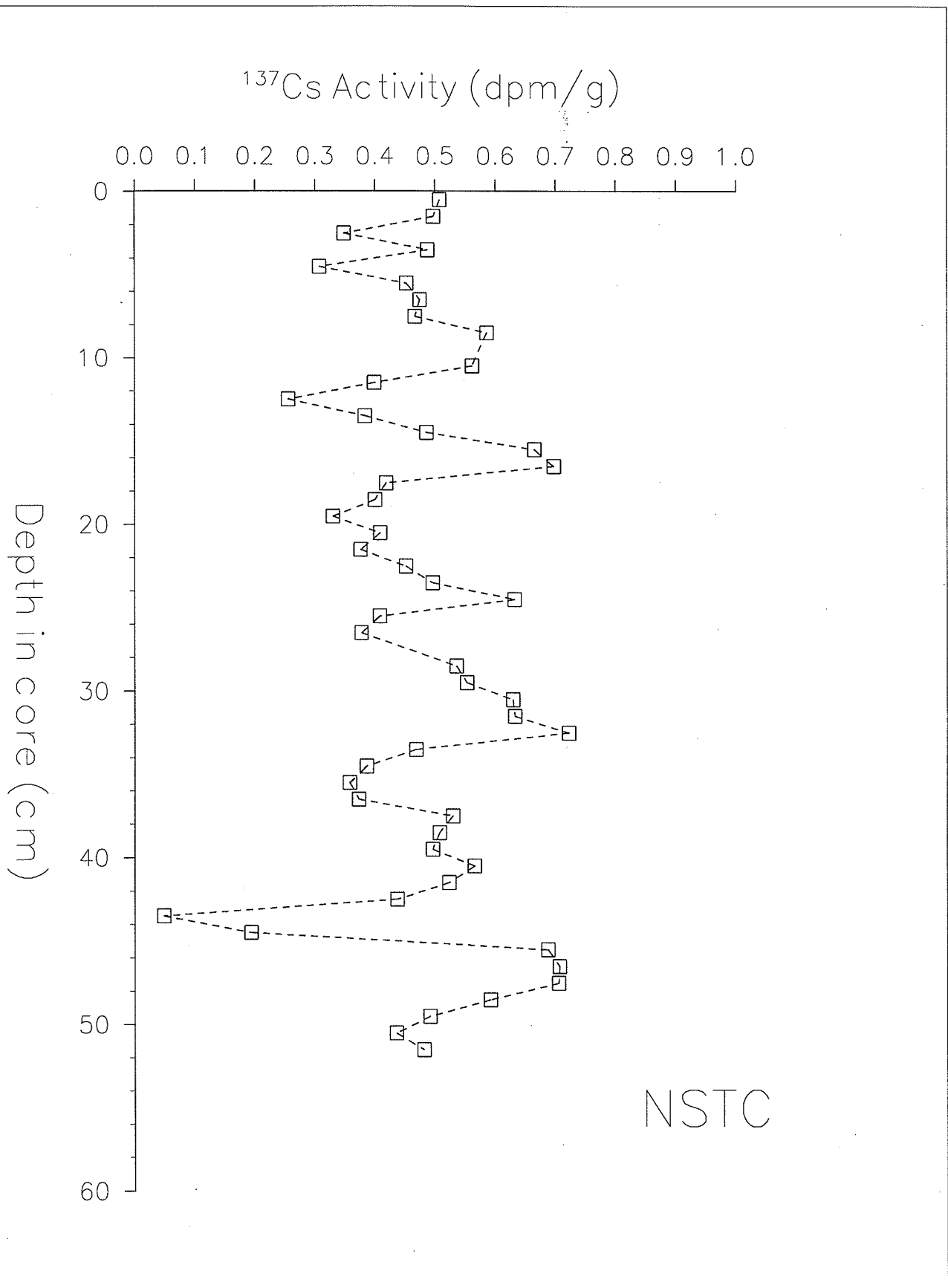
Figure 3. Depth vs. ^{137}Cs Activity—Core C.
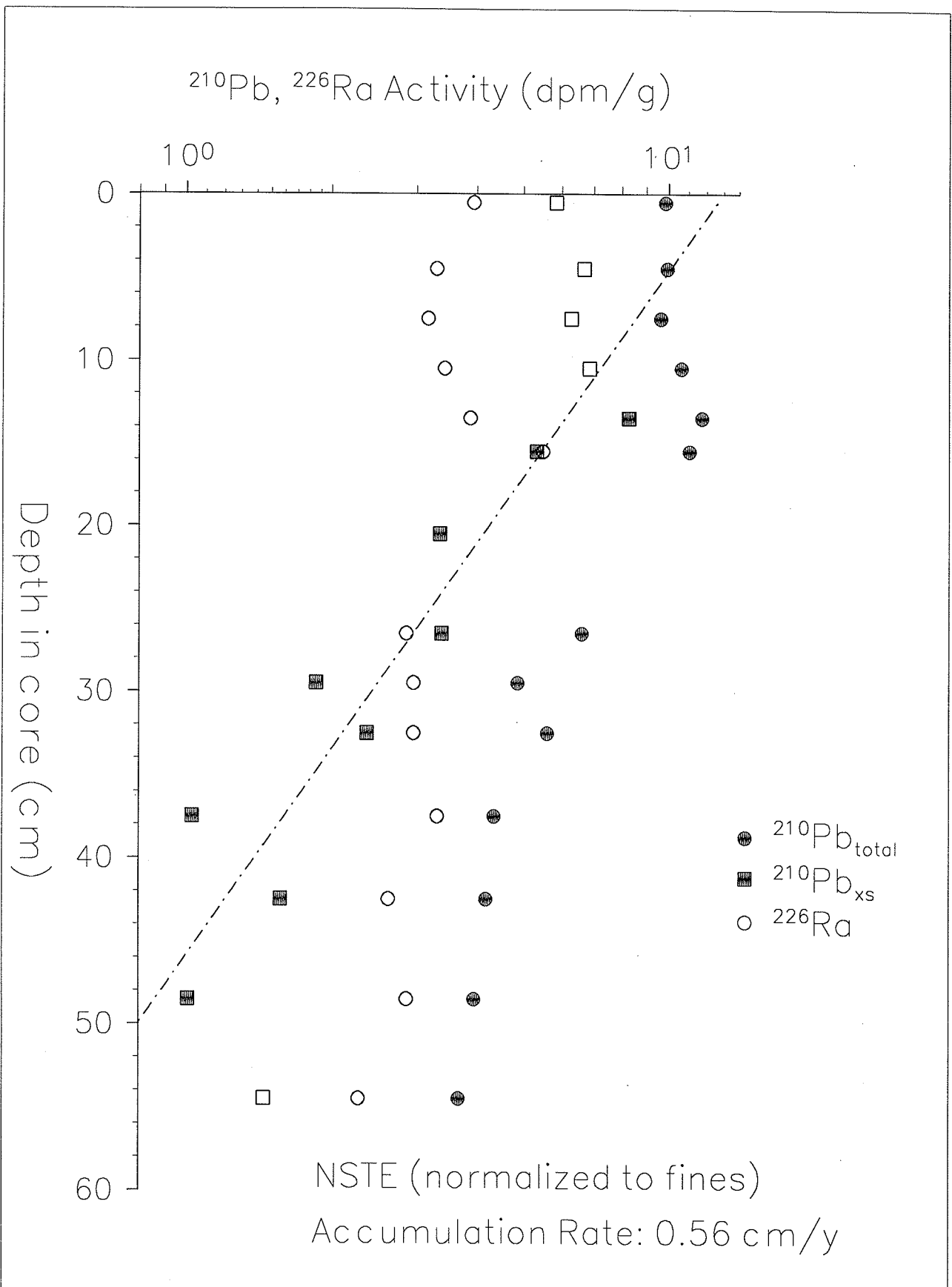
Figure 4. Depth vs. ^{210}Pb and ^{226}Ra Activity—Core E.
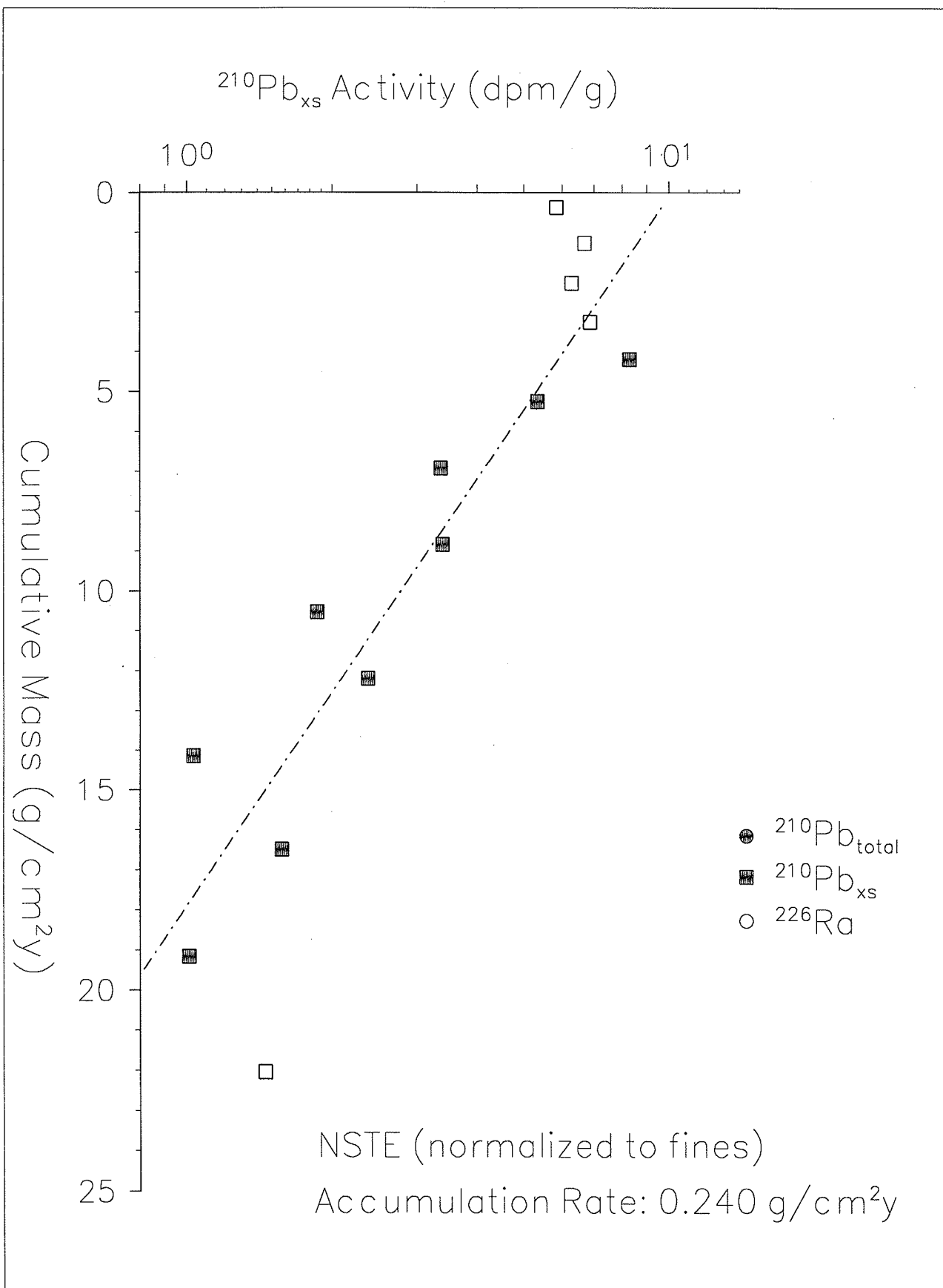
Figure 5. Depth vs. $^{210}Pb_{xs}$ Activity—Core E.
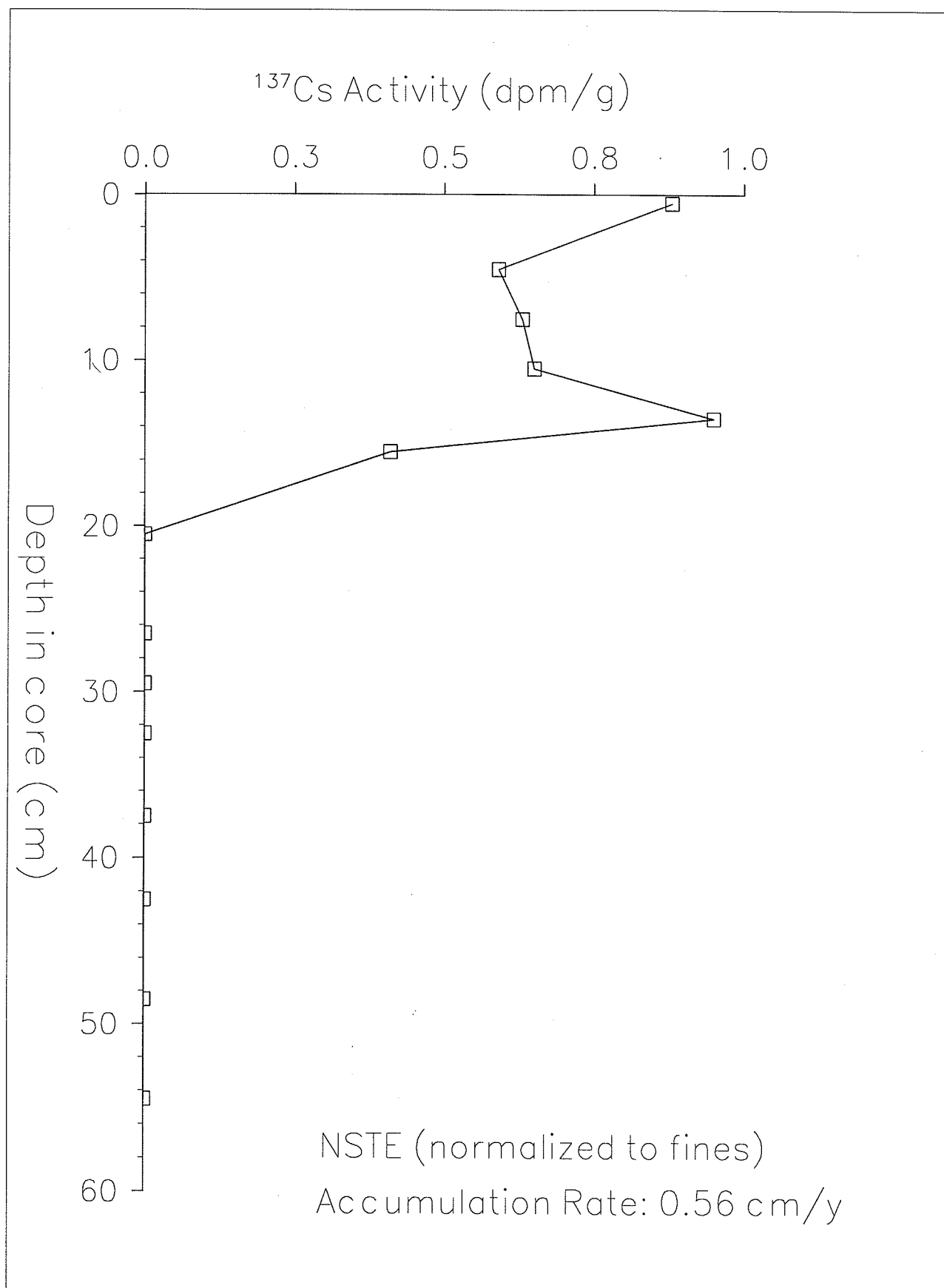
Figure 6. Depth vs. ^{137}Cs Activity—Core E.
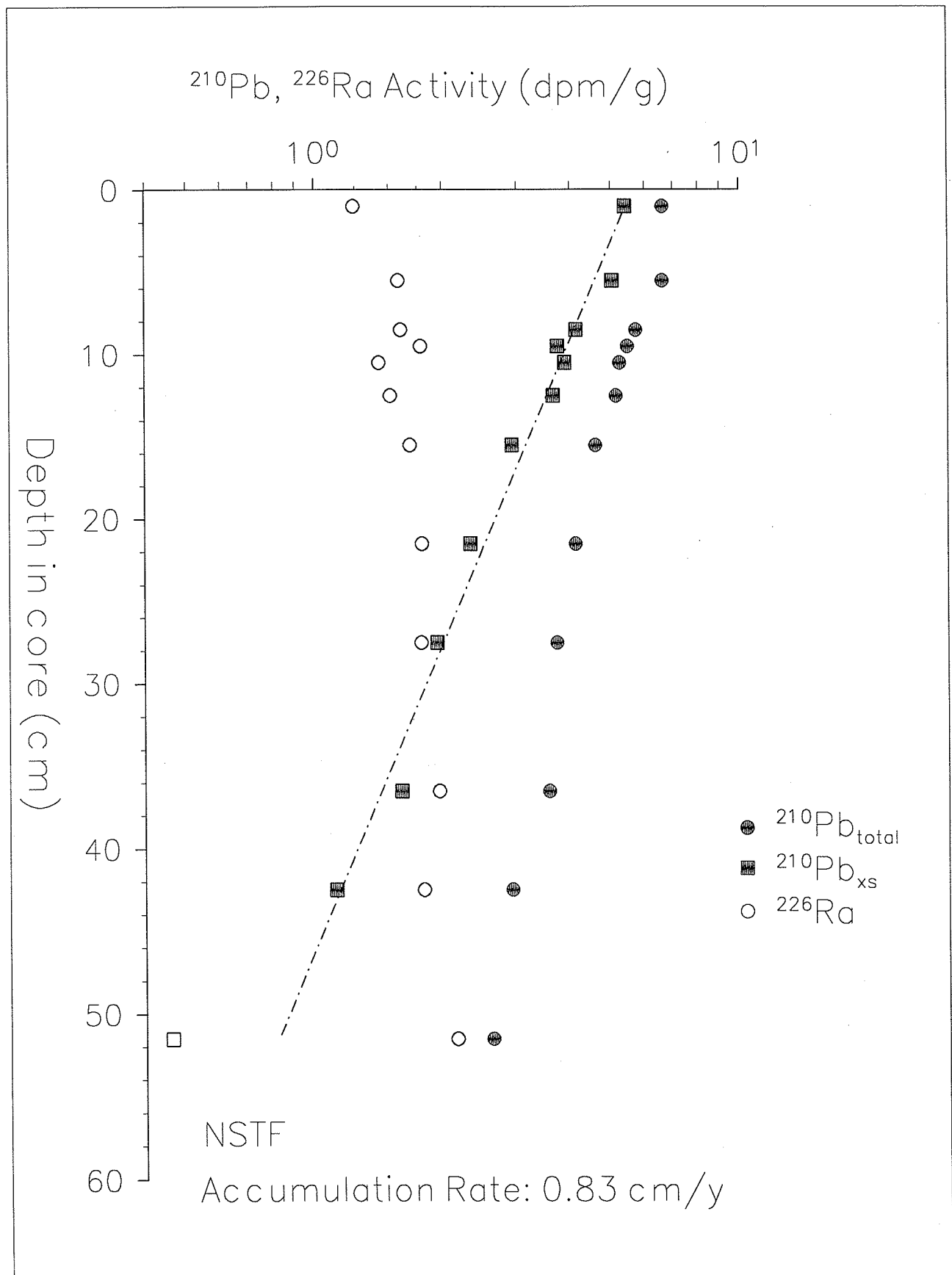
Figure 7. Depth vs. ^{210}Pb and ^{226}Ra Activity—Core F.
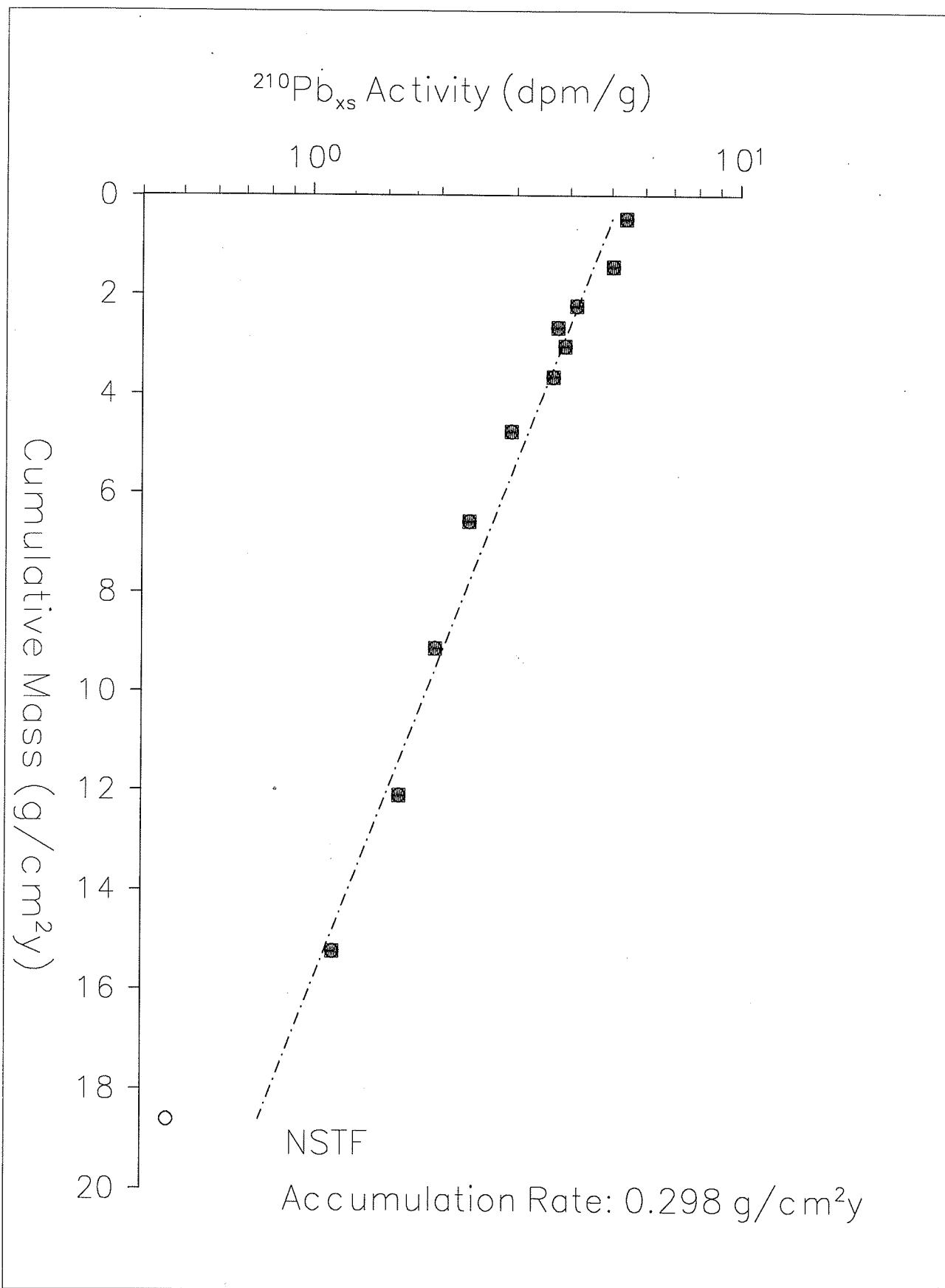
Figure 8. Depth vs. $^{210}Pb_{xs}$ and Activity—Core F.
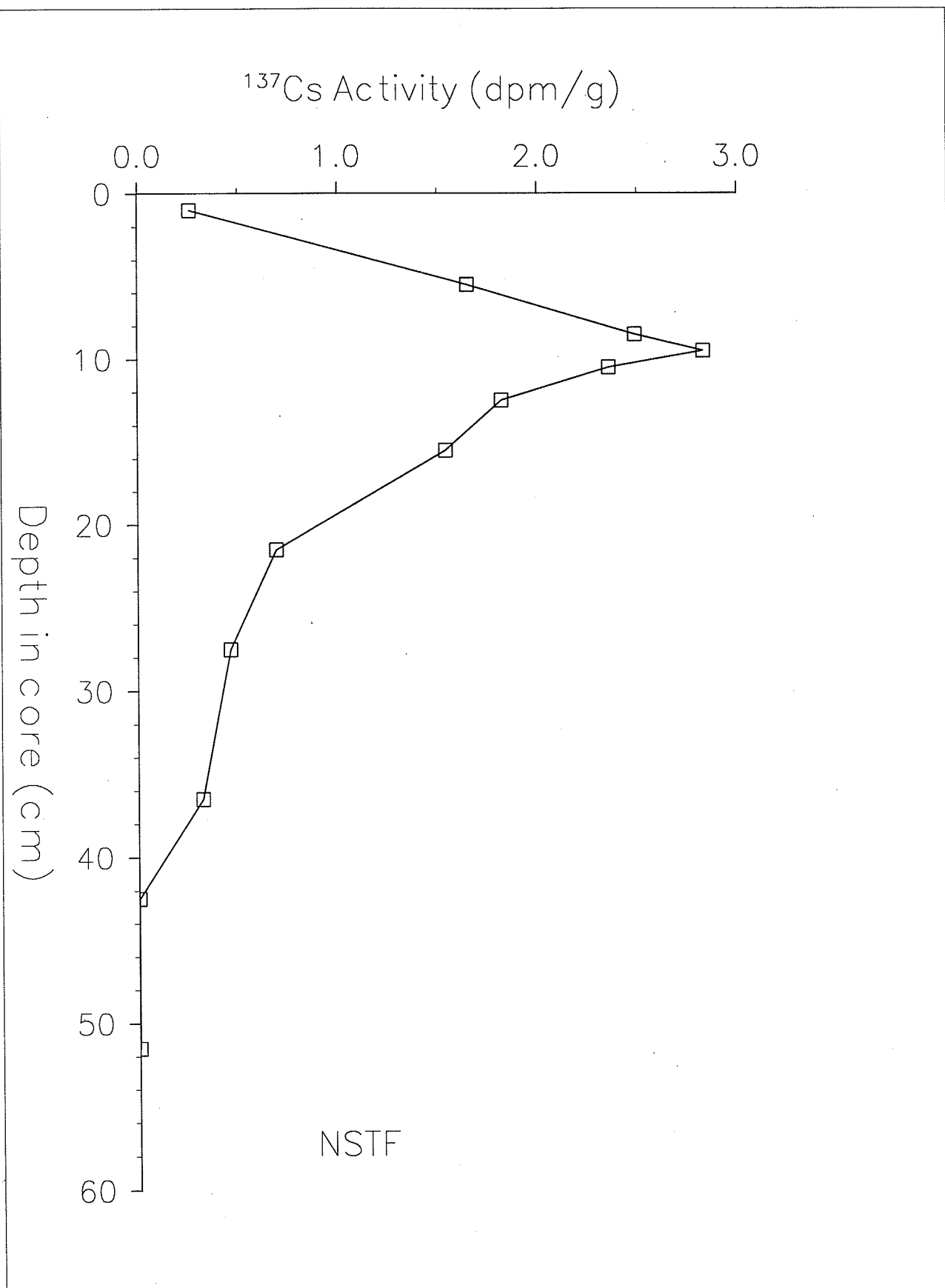
Figure 9. Depth vs. ^{137}Cs and Activity—Core F.
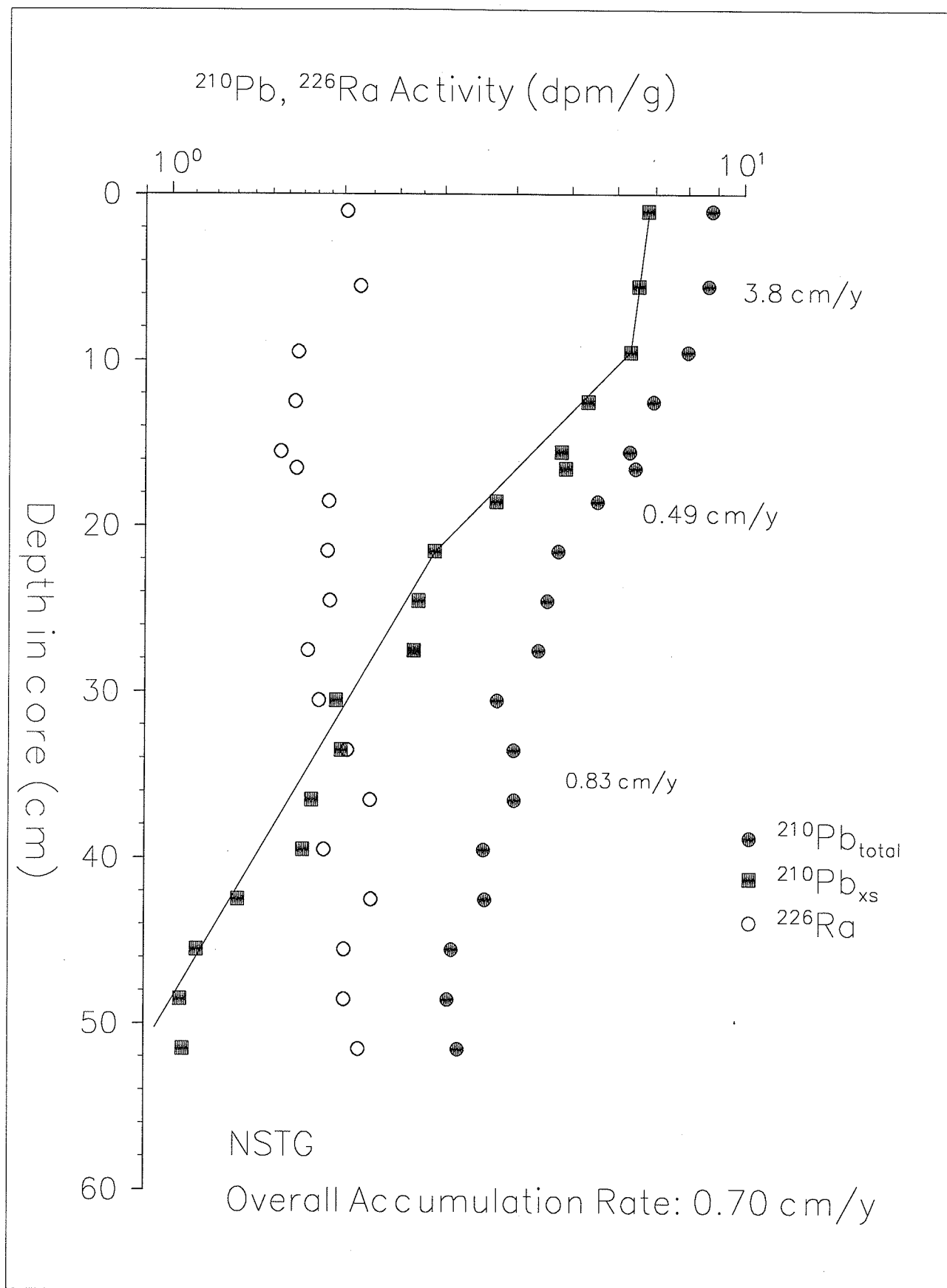
Figure 10. Depth vs. ^{210}Pb and ^{226}Ra Activity—Core G.
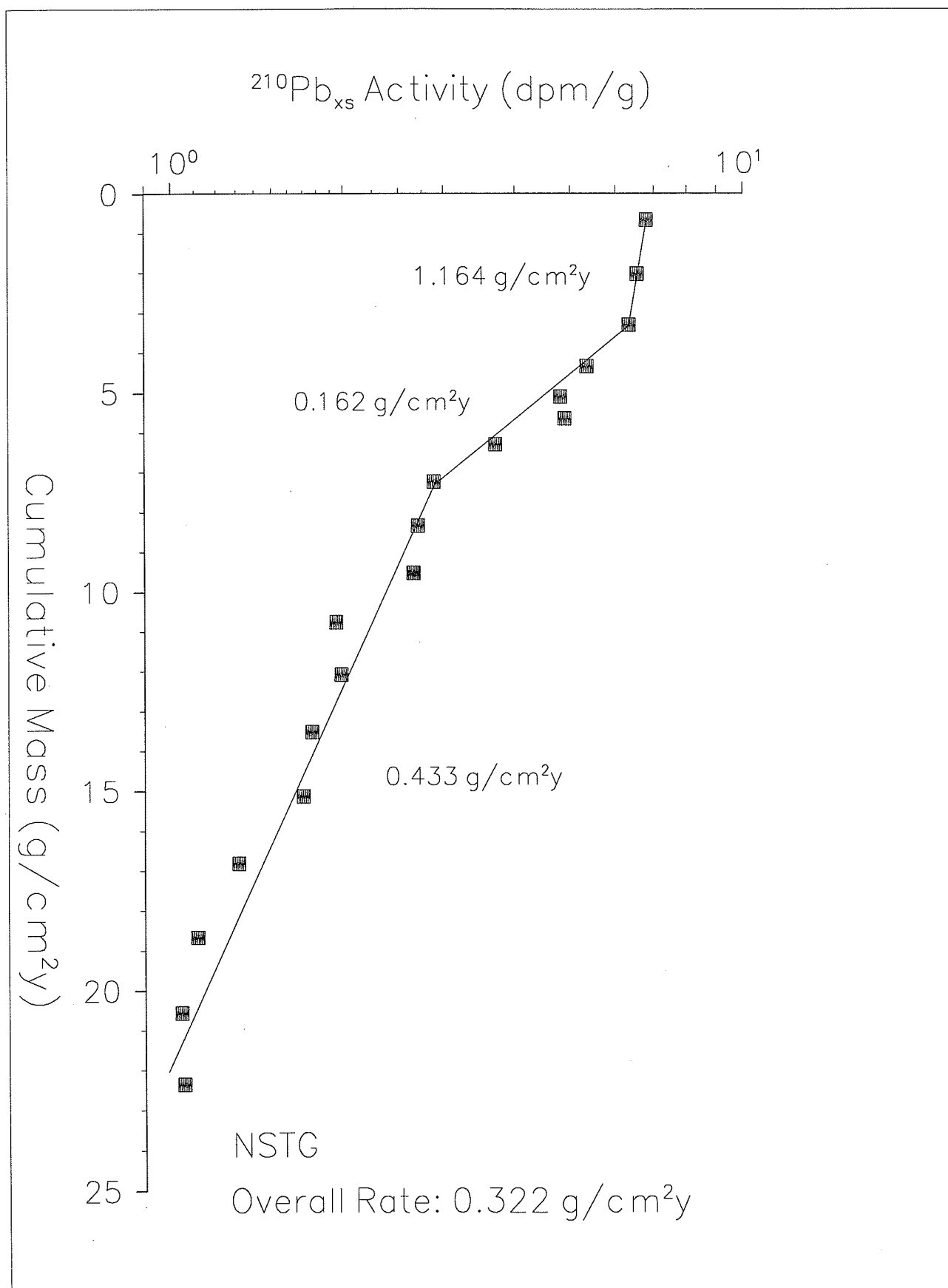
Figure 11. Cumulative Dry Mass vs. $^{210}Pb_{xs}$ Activity—Core G.
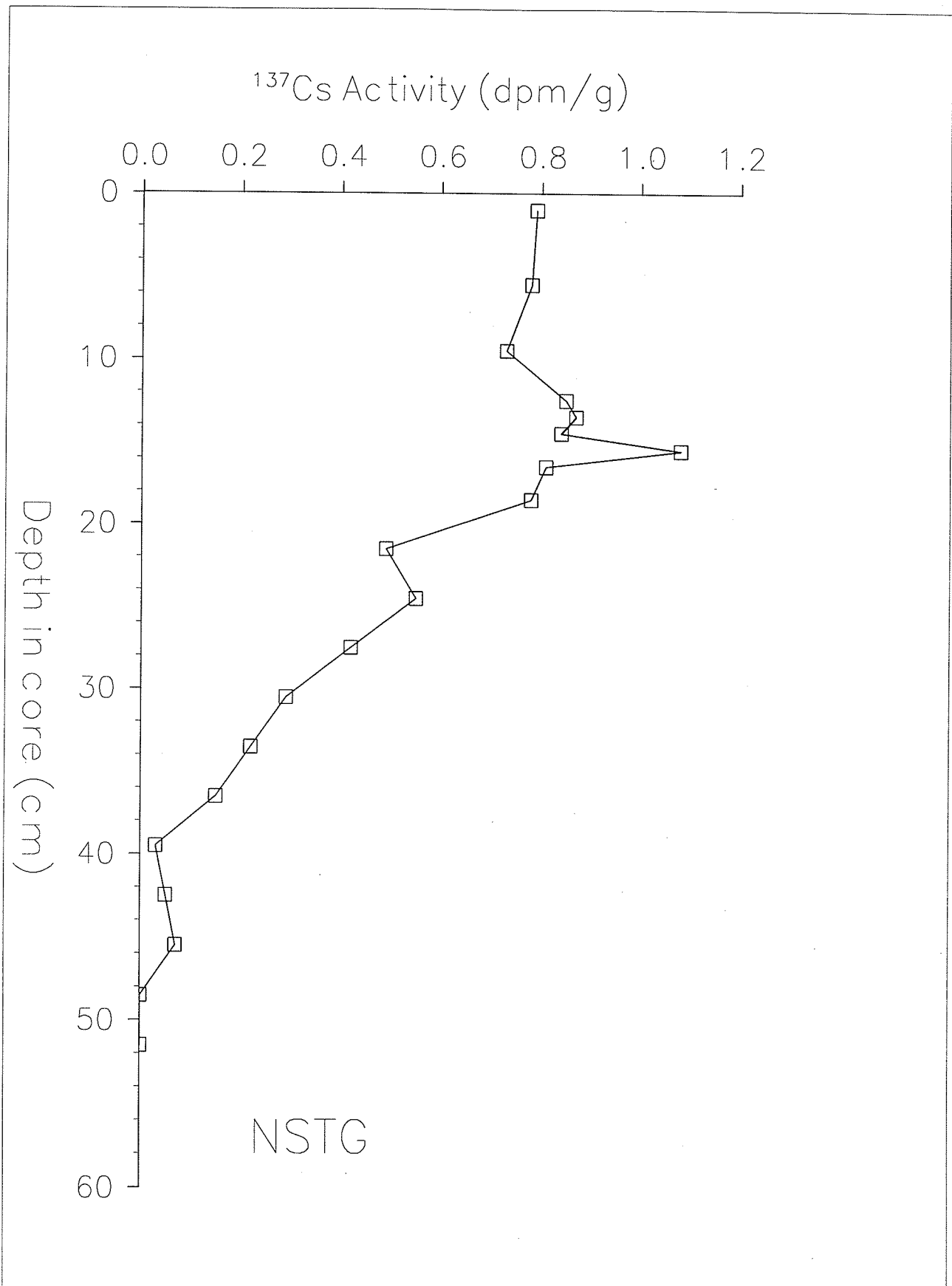
Figure 12. Depth vs. ^{137}Cs Activity—Core G.
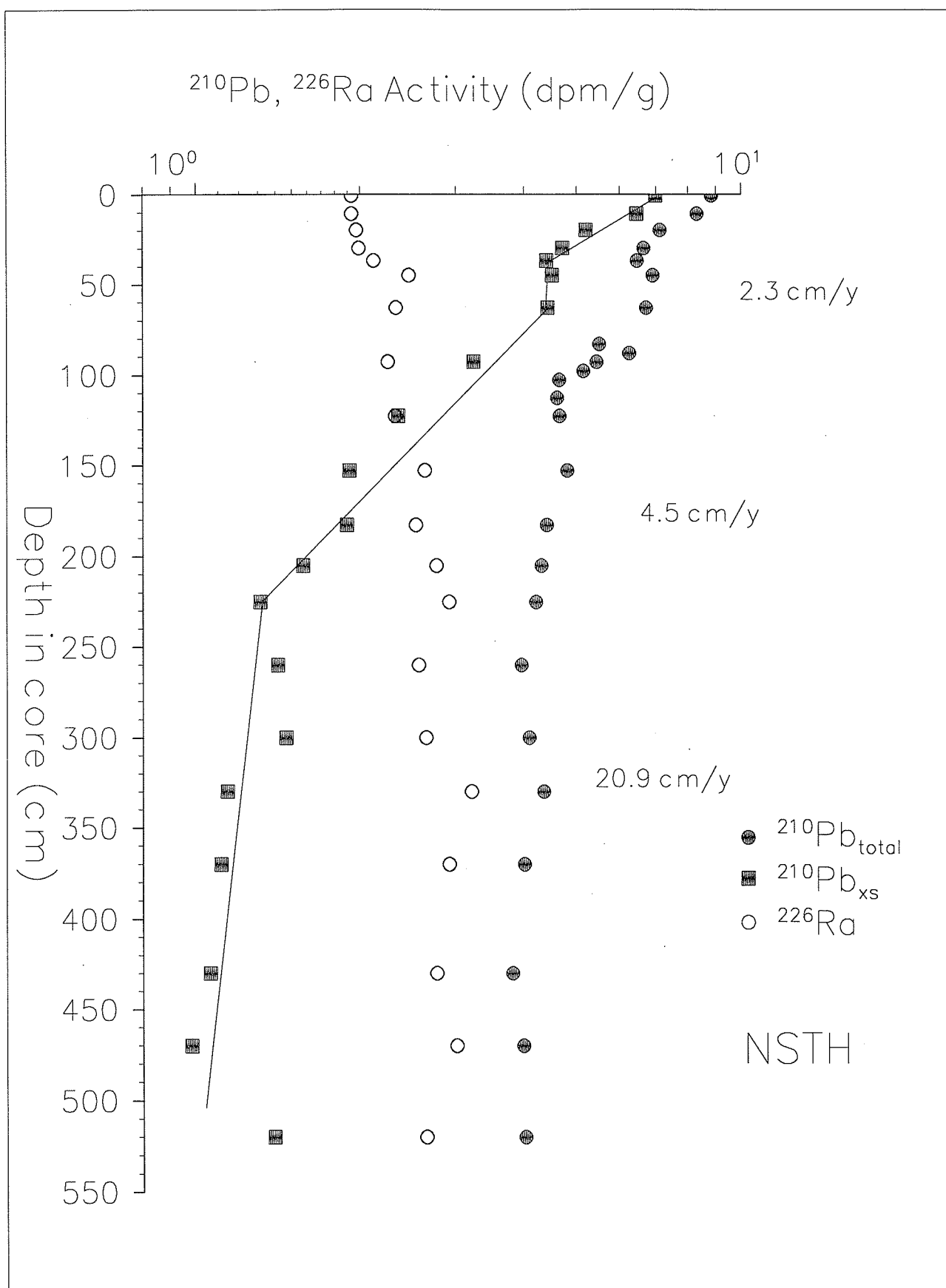
Figure 13. Depth vs. ^{210}Pb and ^{226}Ra Activity—Core H.
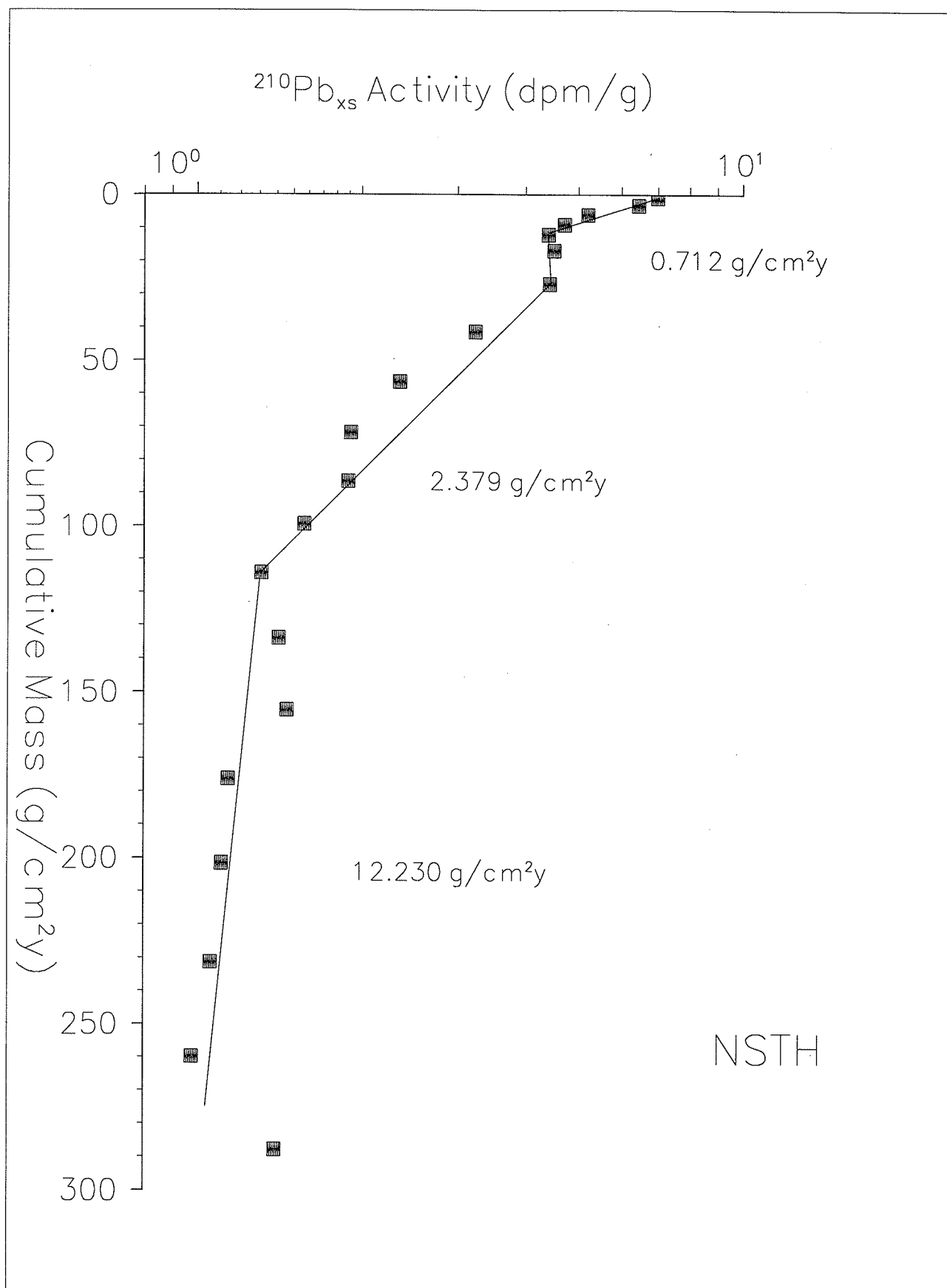
Figure 14. Cumulative Dry Mass vs. $^{210}Pb_{xs}$ Activity—Core H.
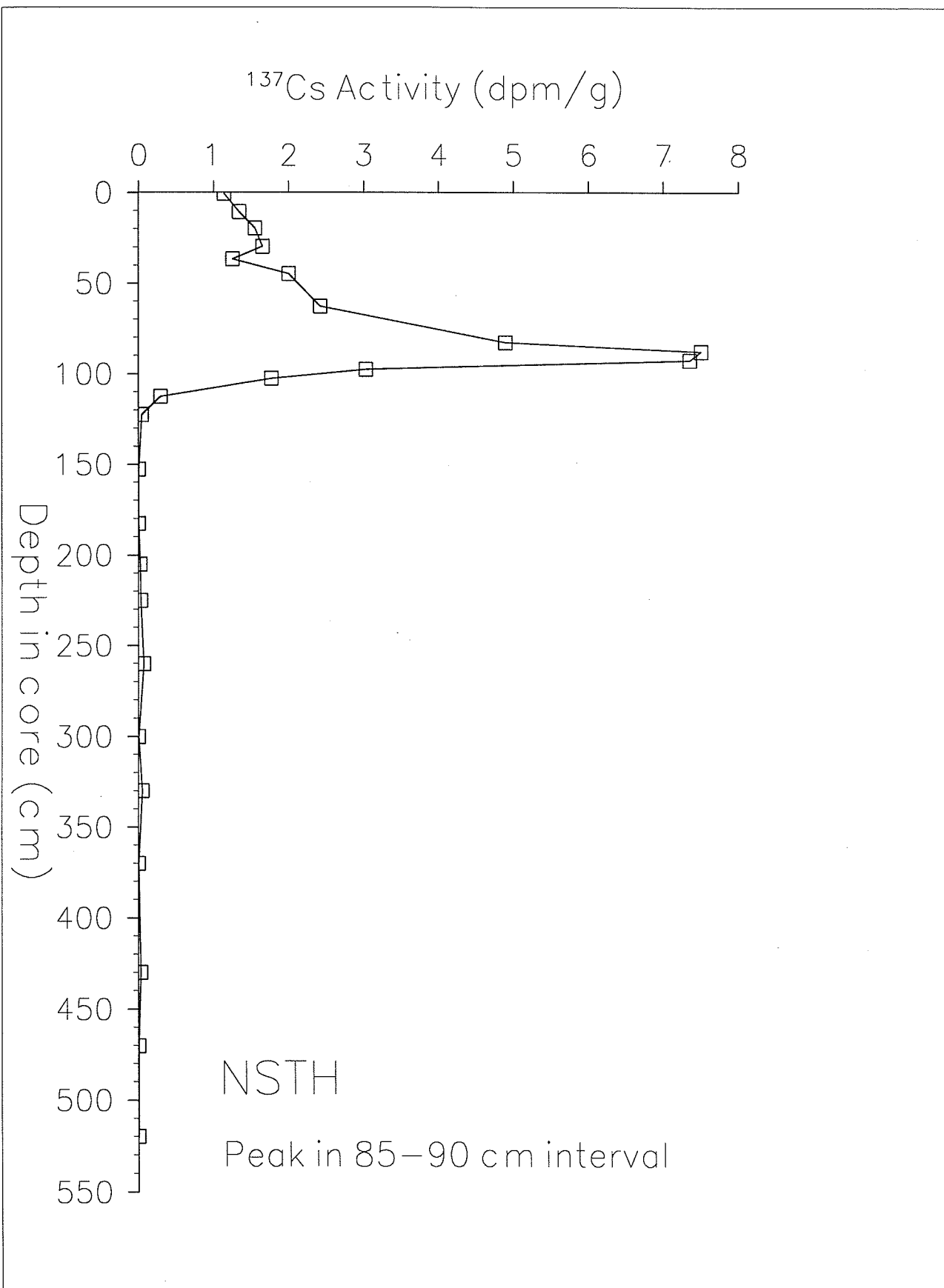
Figure 15. Depth vs. ^{137}Cs Activity—Core H.
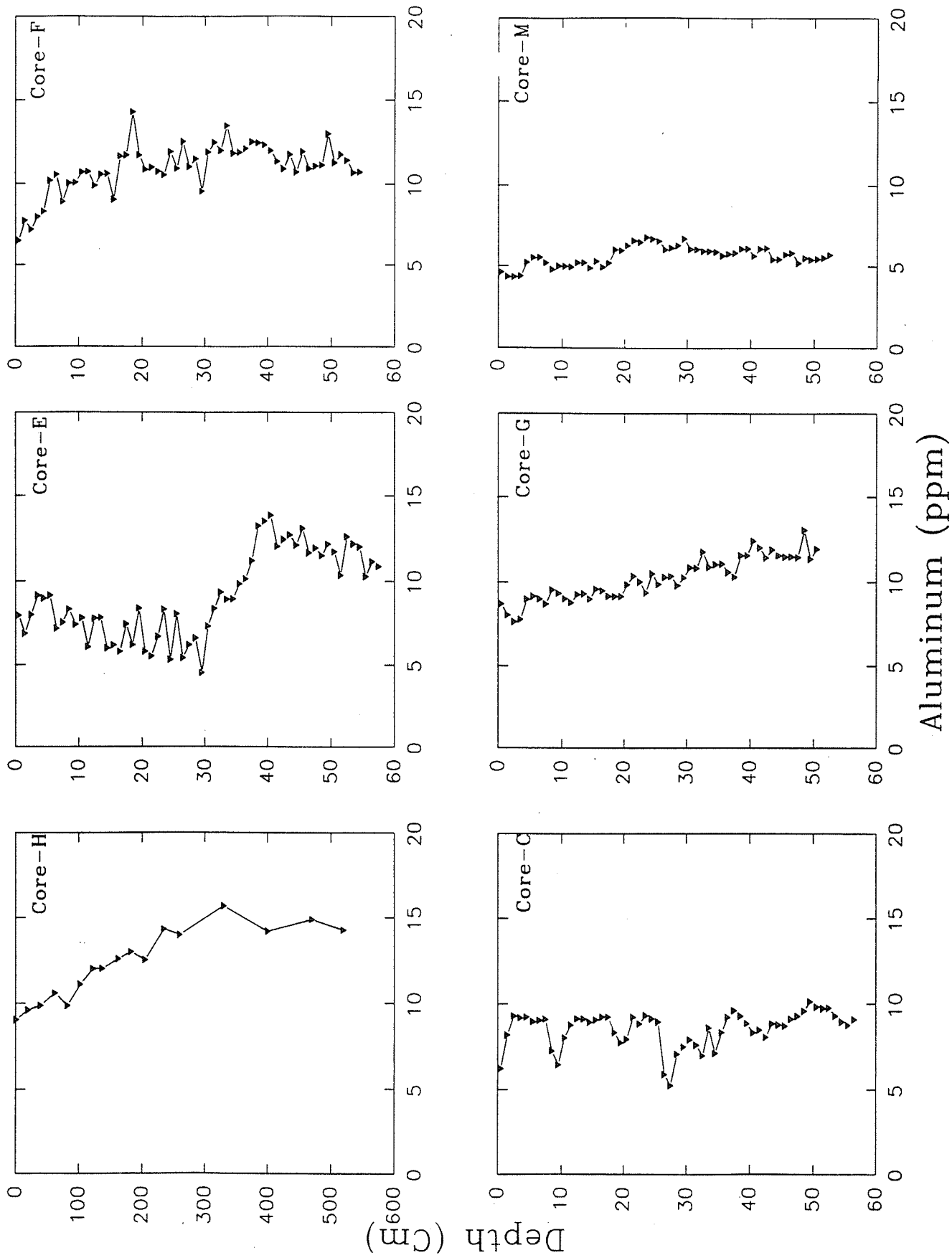
Figure 16. Aluminum Concentration versus Sediment Depth
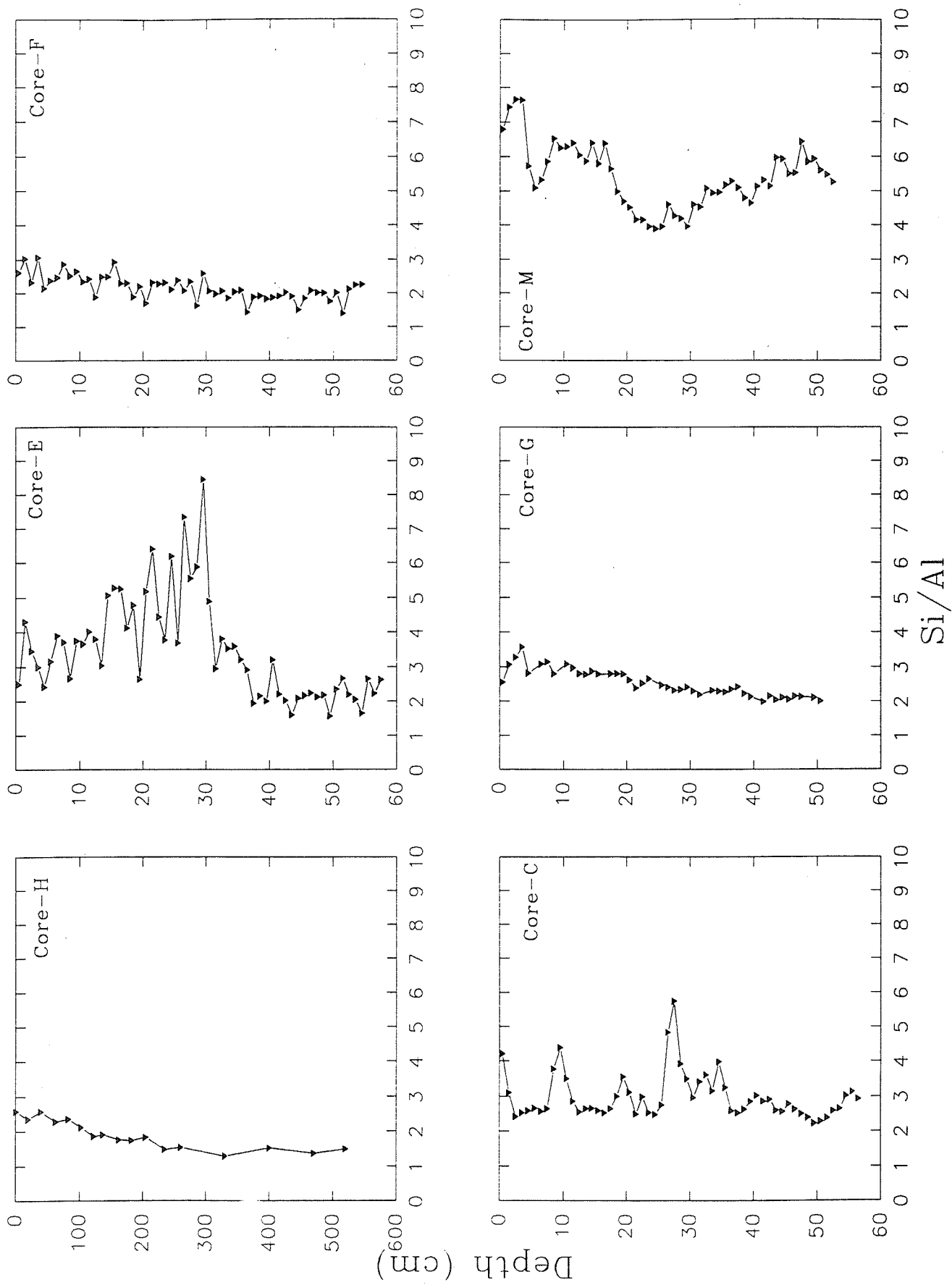
Figure 17. Si/Al versus Sediment Depth
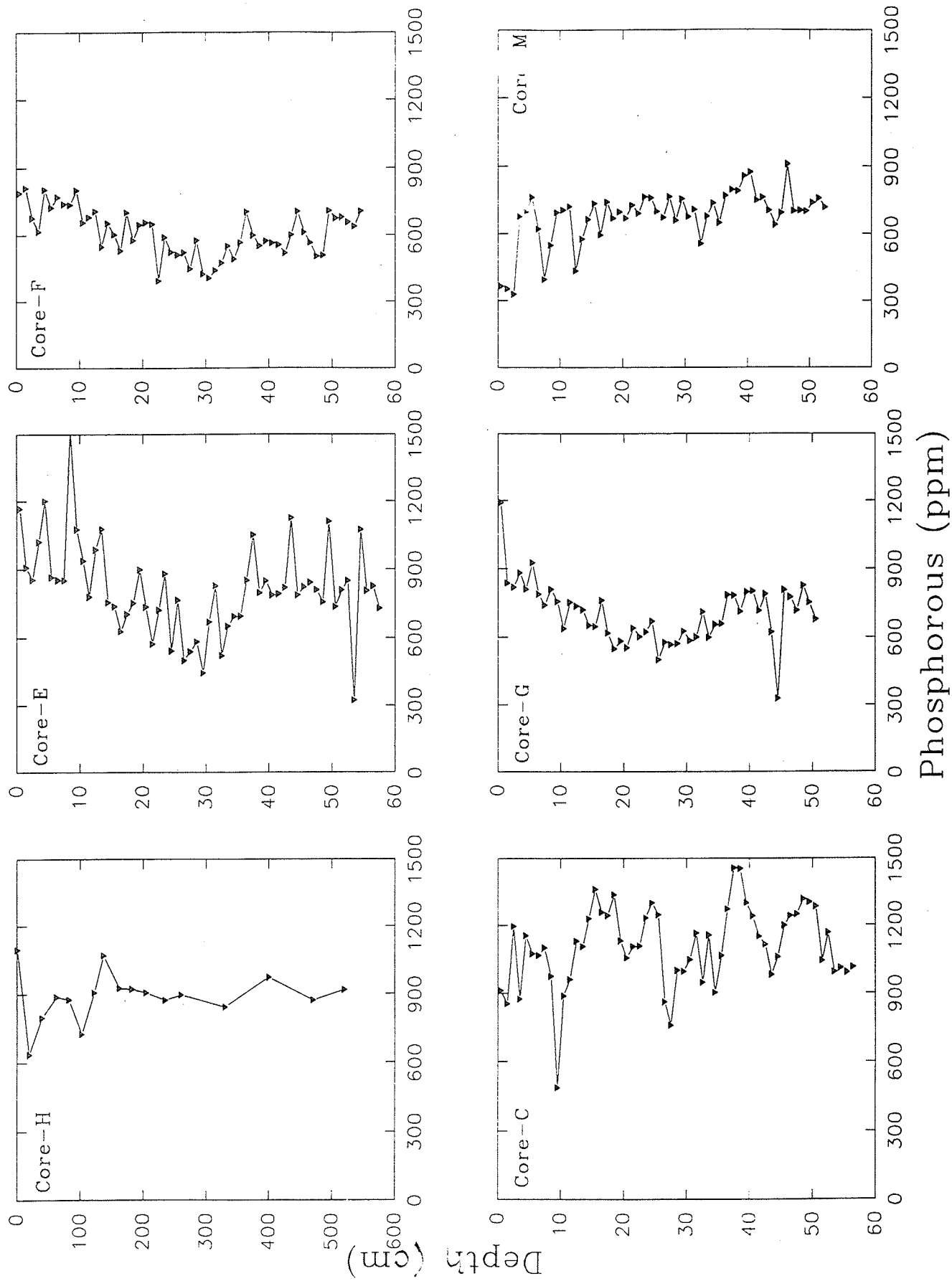
Figure 18. Phosphorus Concentration versus Sediment Depth
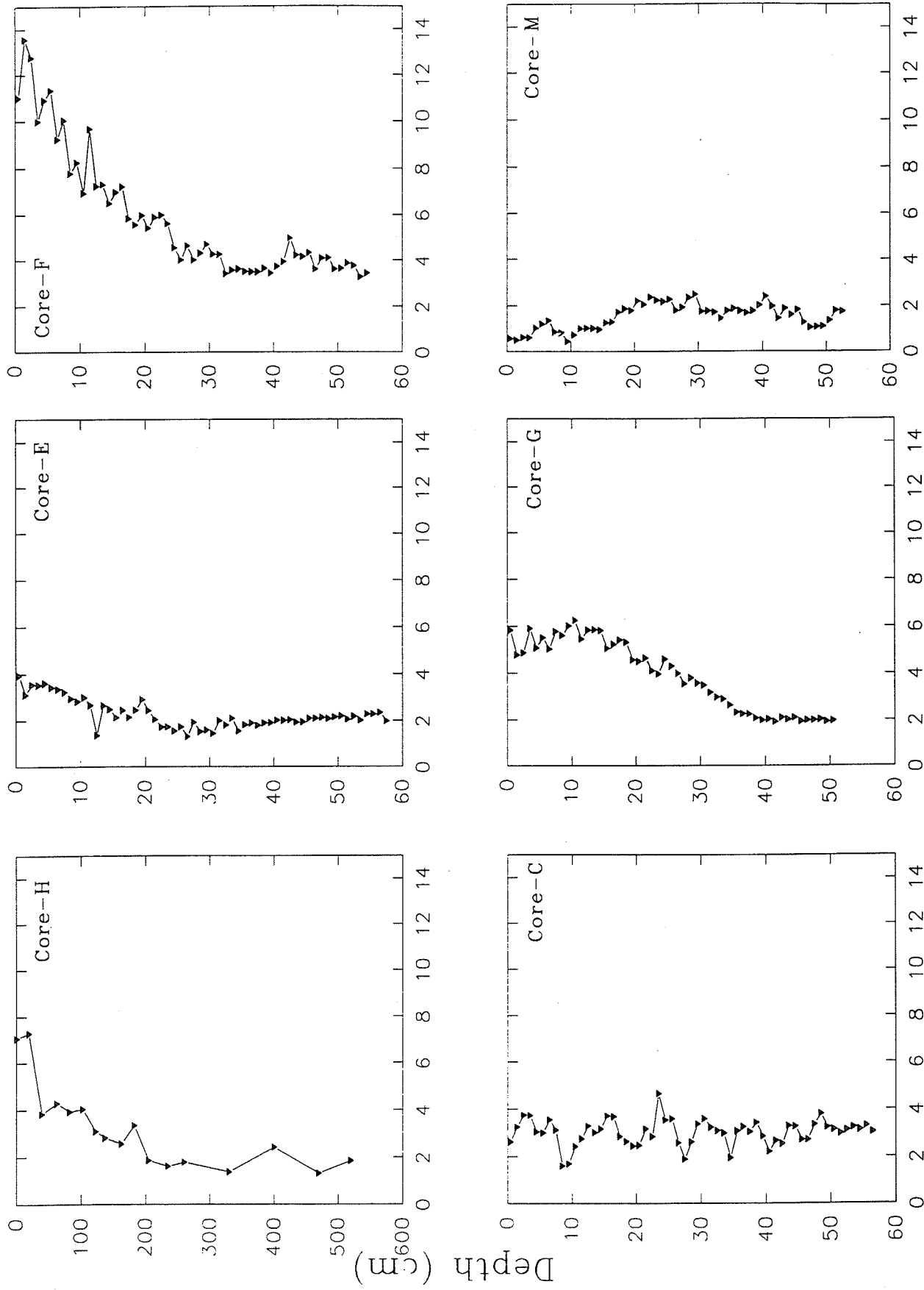
Figure 19. Organic Carbon Concentration versus Depth in Sediments
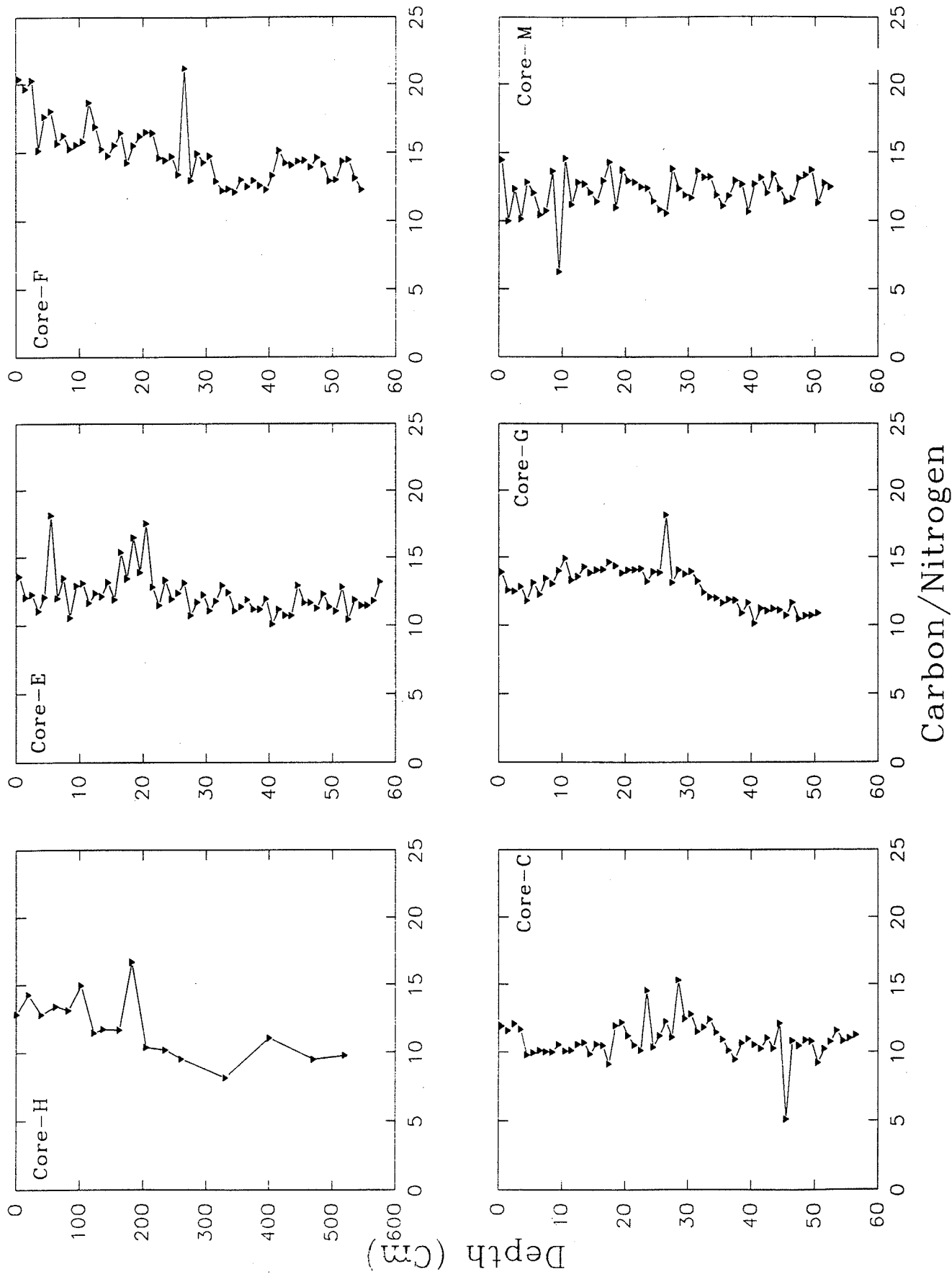
Figure 20. Organic Carbon:Nitrogen versus Depth in Sediments
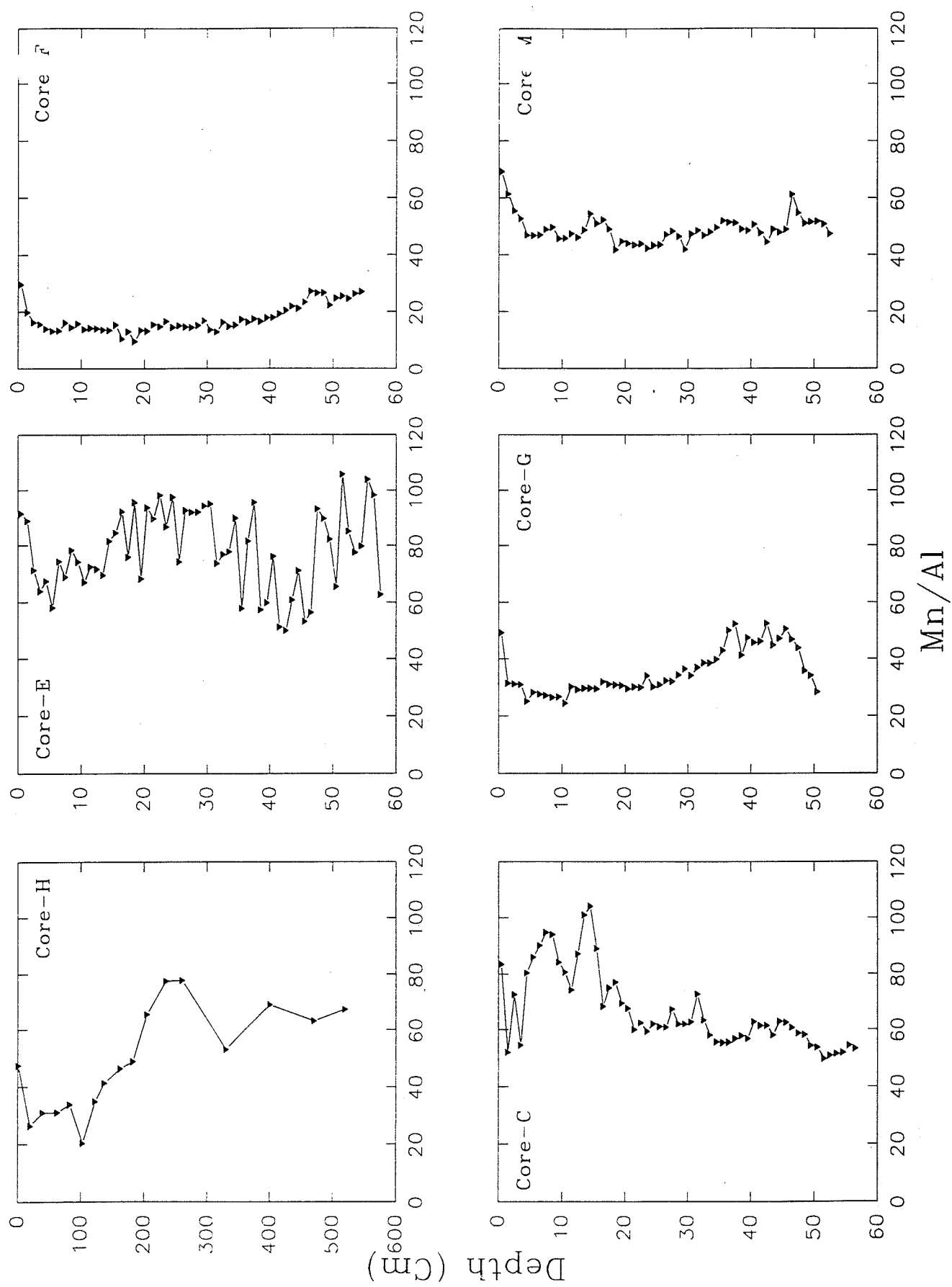
Figure 21. Mn/Al ratios versus depth in Sediments
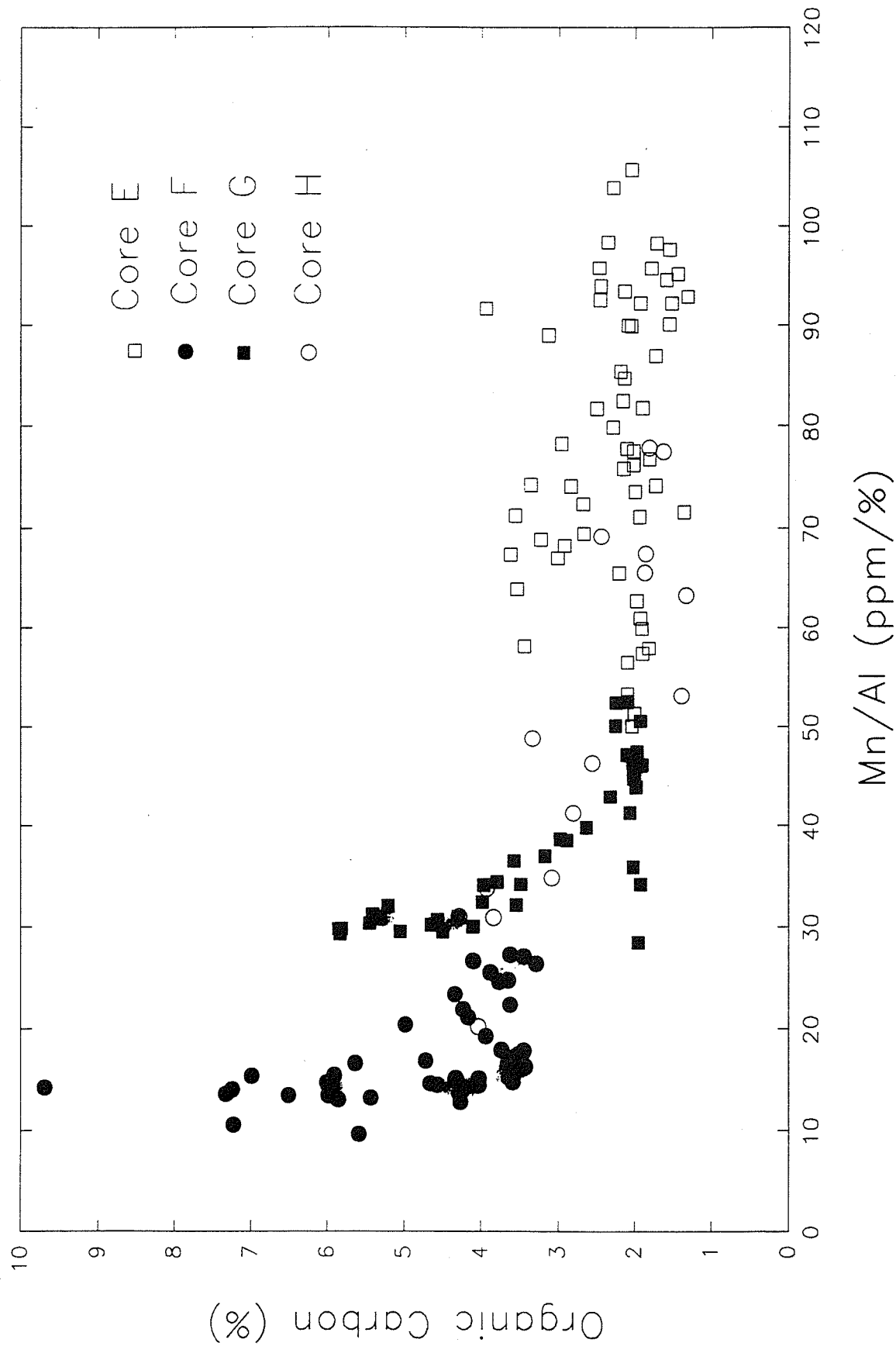
Figure 22. Organic Carbon versus Mn/Al Ratios in Sediments
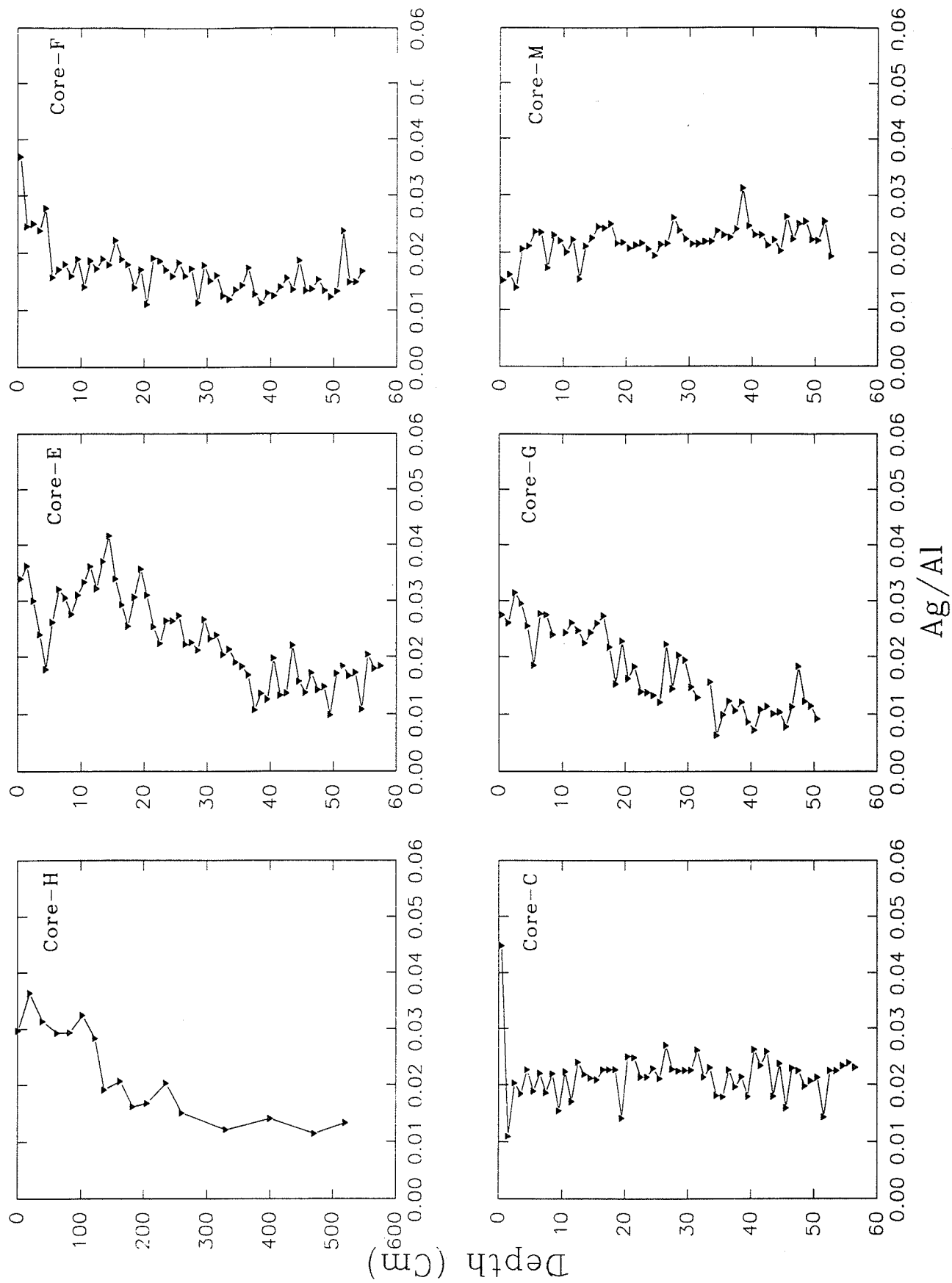
Figure 23. Ag/Al (x10⁴) versus Depth in Sediments
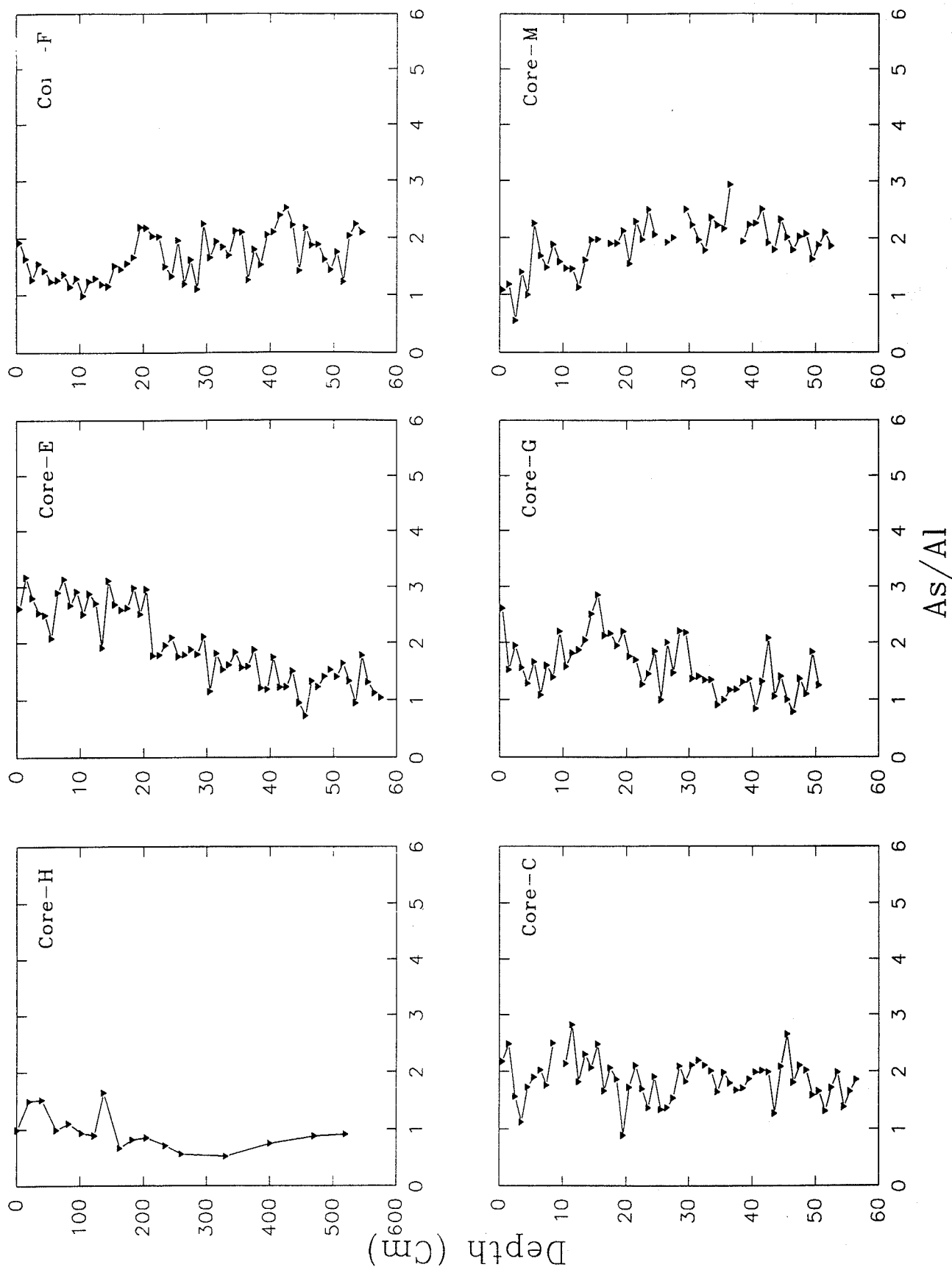
Figure 24. As/Al (x10^4) versus Depth in Sediments
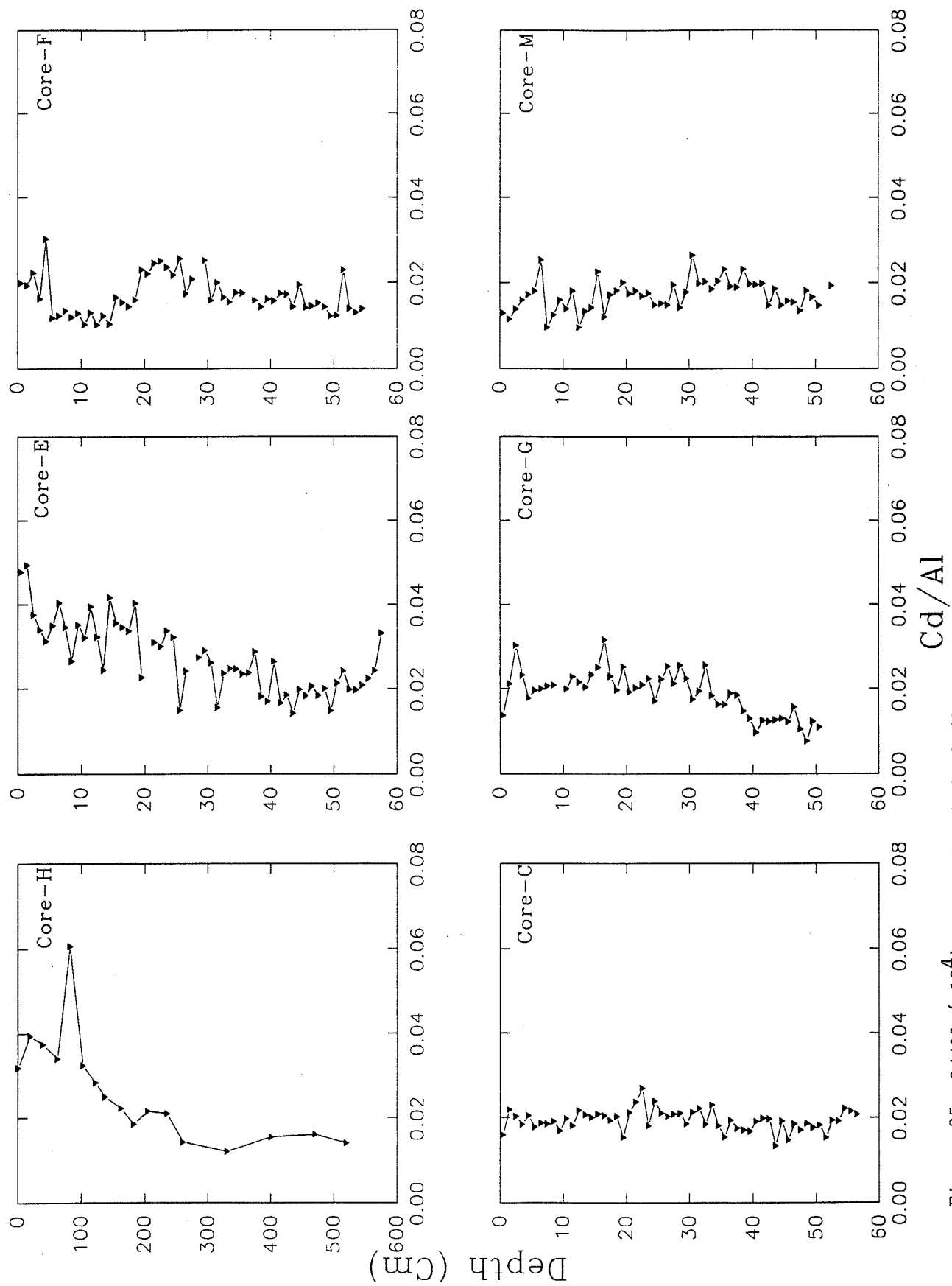
Figure 25. Cd/Al ($\times 10^4$) versus Depth in Sediments
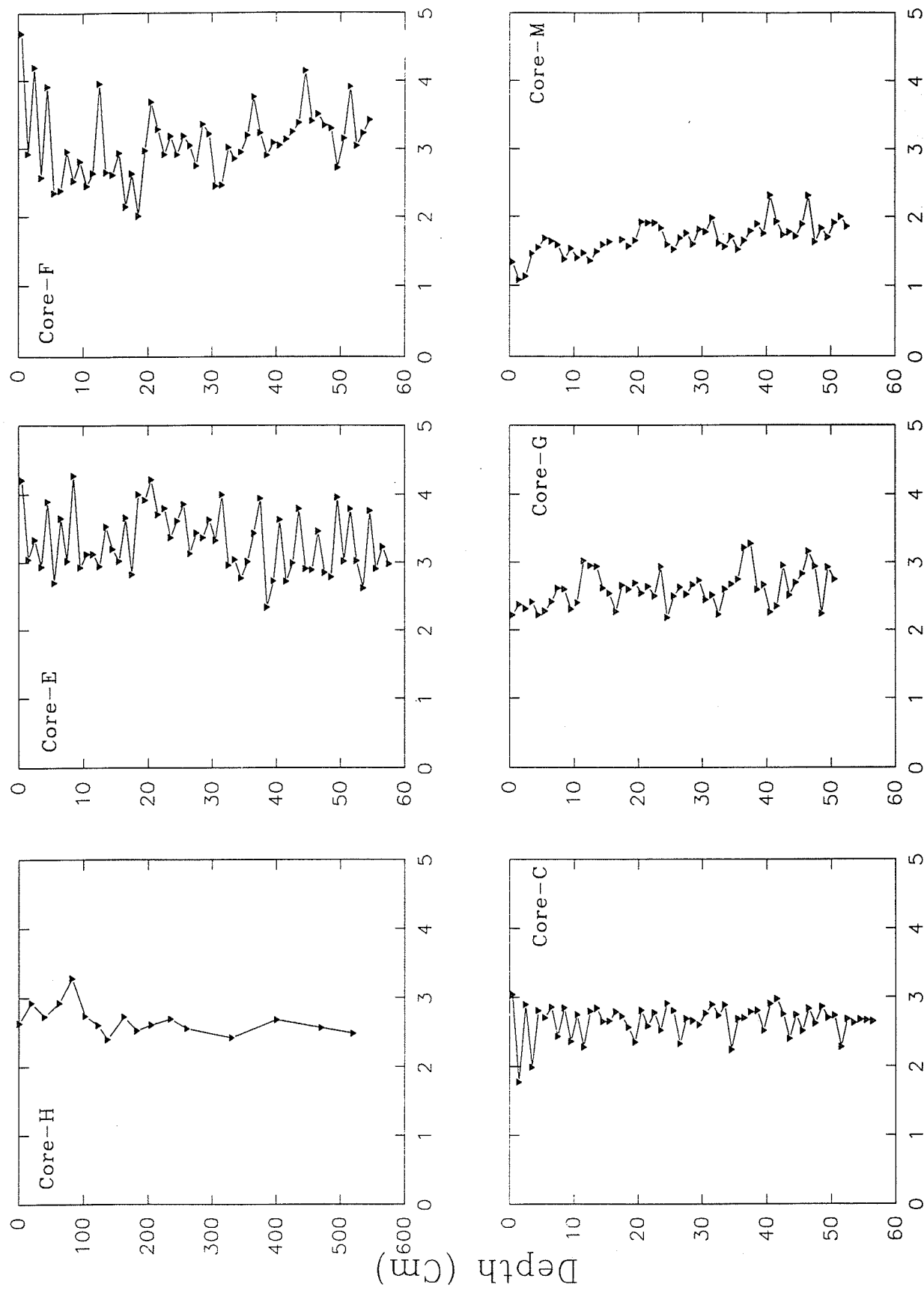
Figure 26. Cu/Al (x10^4) versus Depth in Sediments
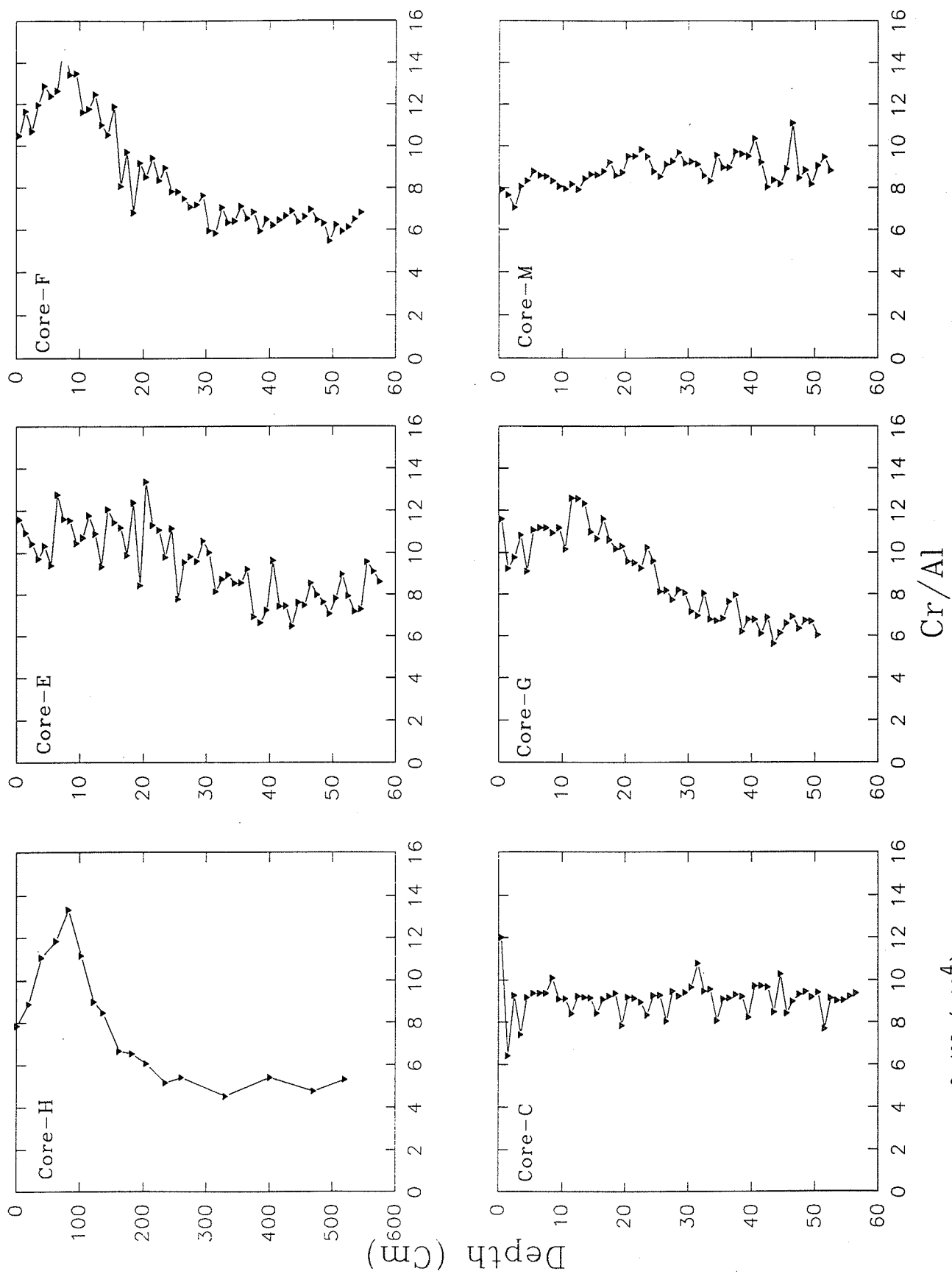
Figure 27. Cr/Al (x10⁴) versus depth in sediments
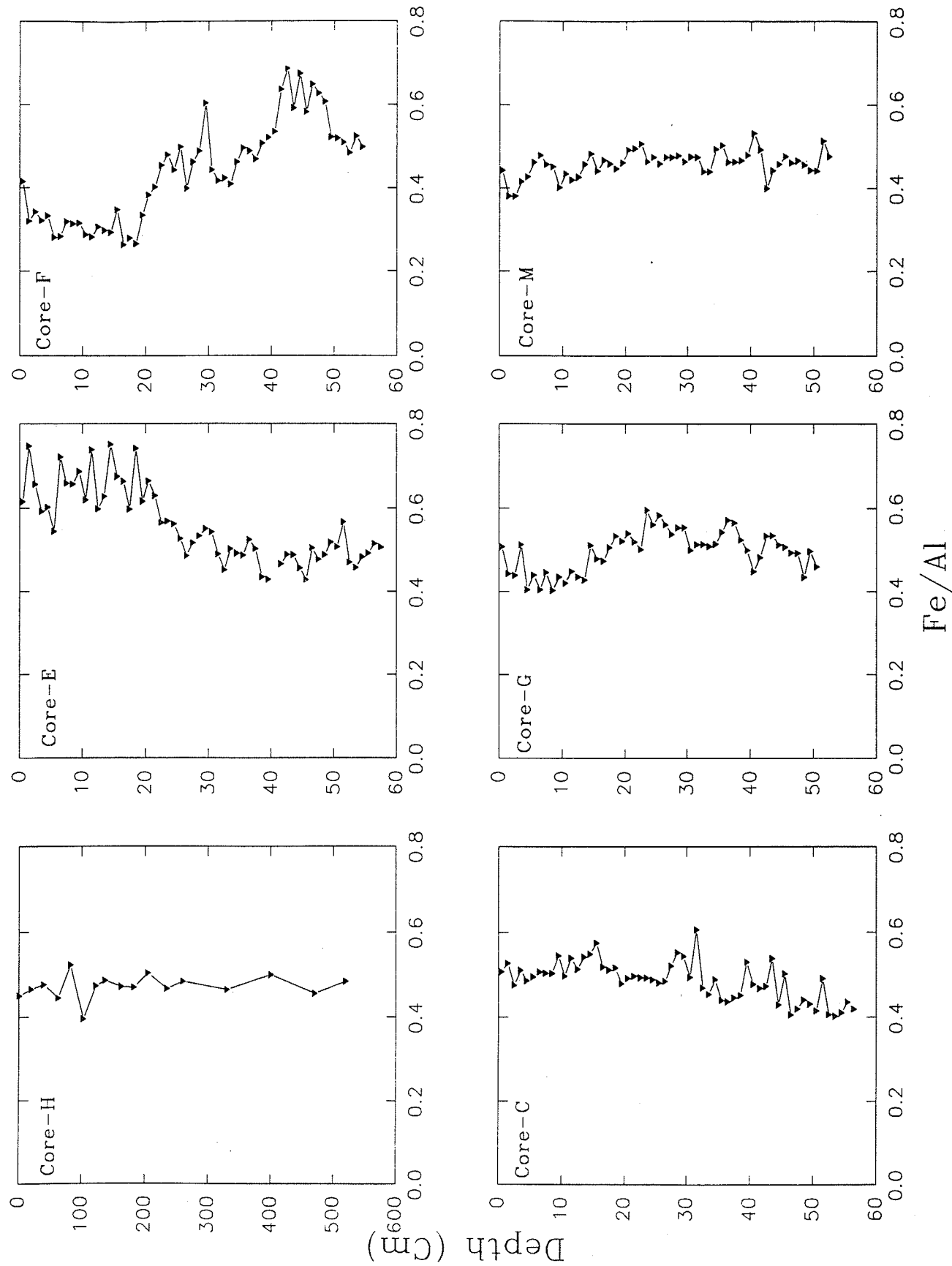
Figure 28. Fe/Al versus depth in Sediments
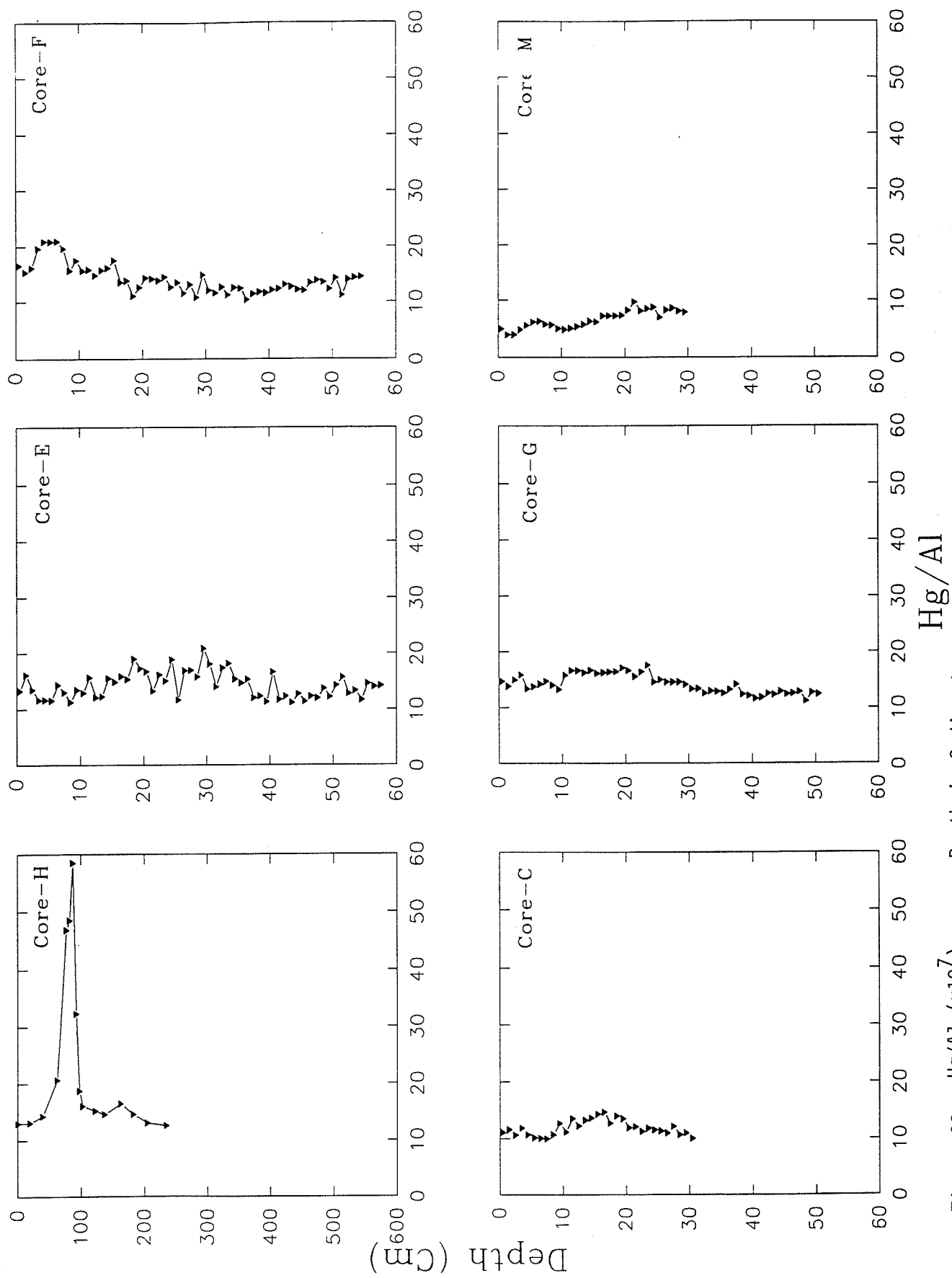
Figure 29. Hg/Al (x10^7) versus Depth in Sediments
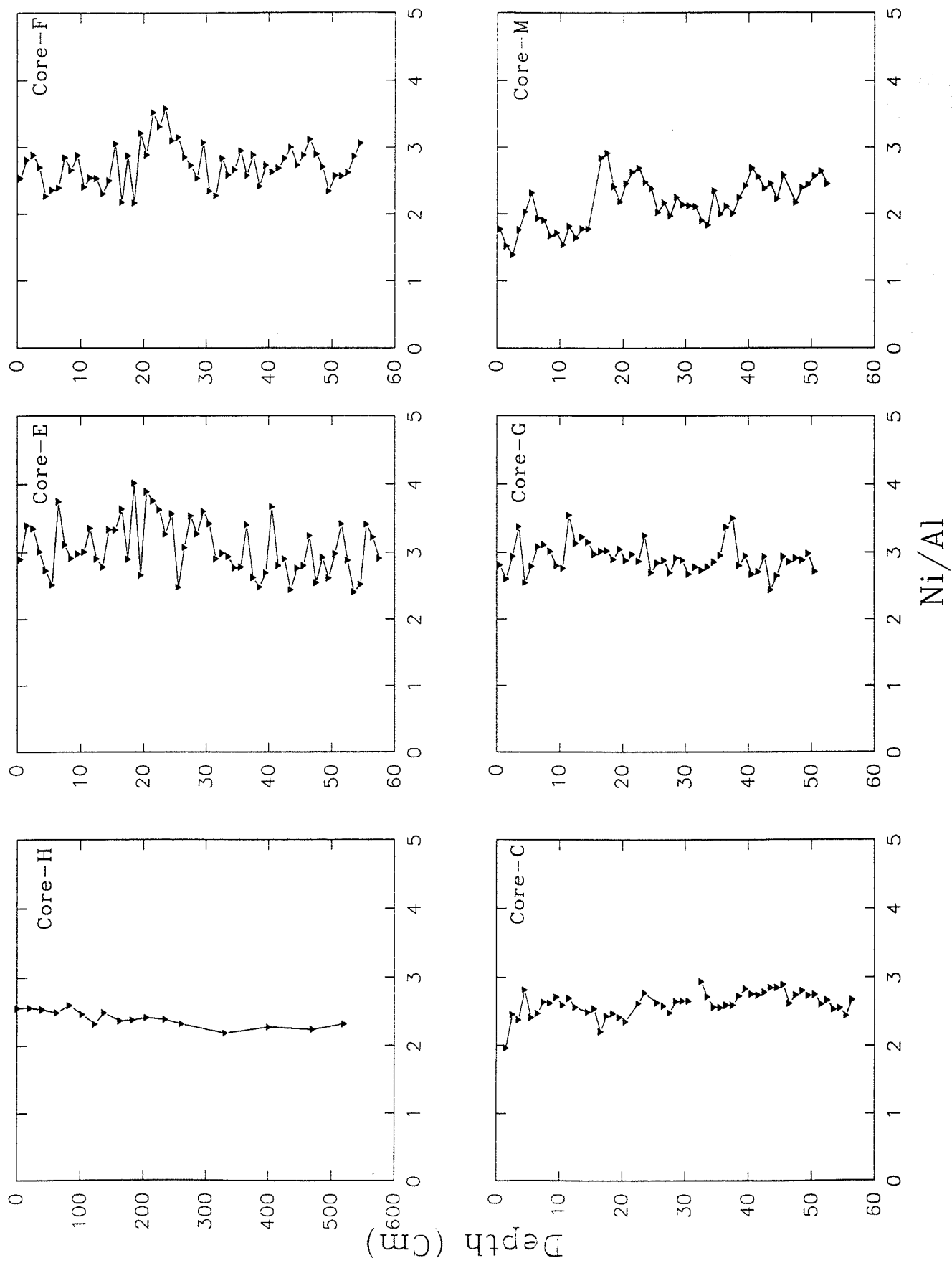
Figure 30. Ni/Al (x10^4) versus Depth in Sediments
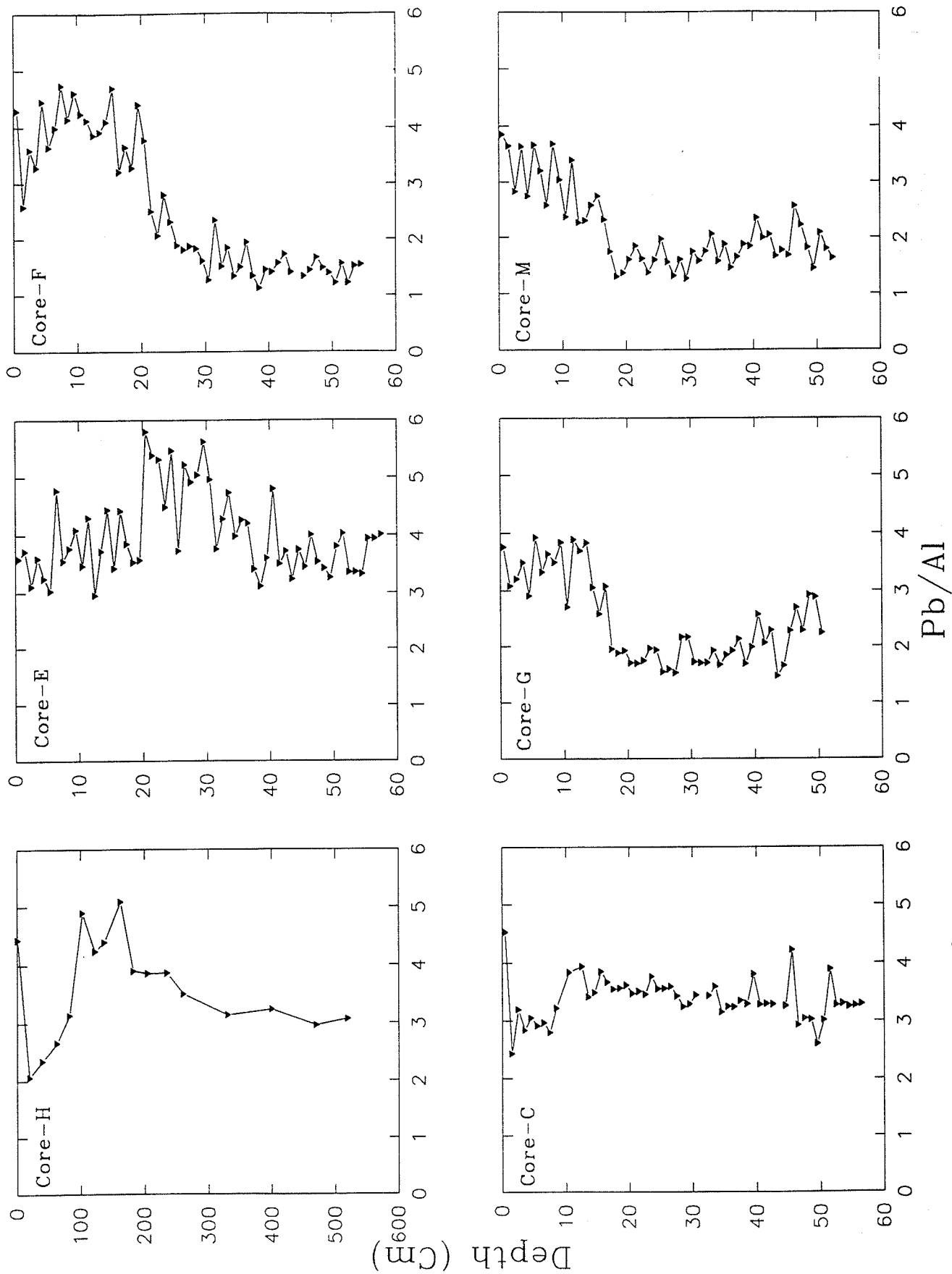
Figure 31. Pb/Al $(\times 10^4)$ versus Depth in Sediments
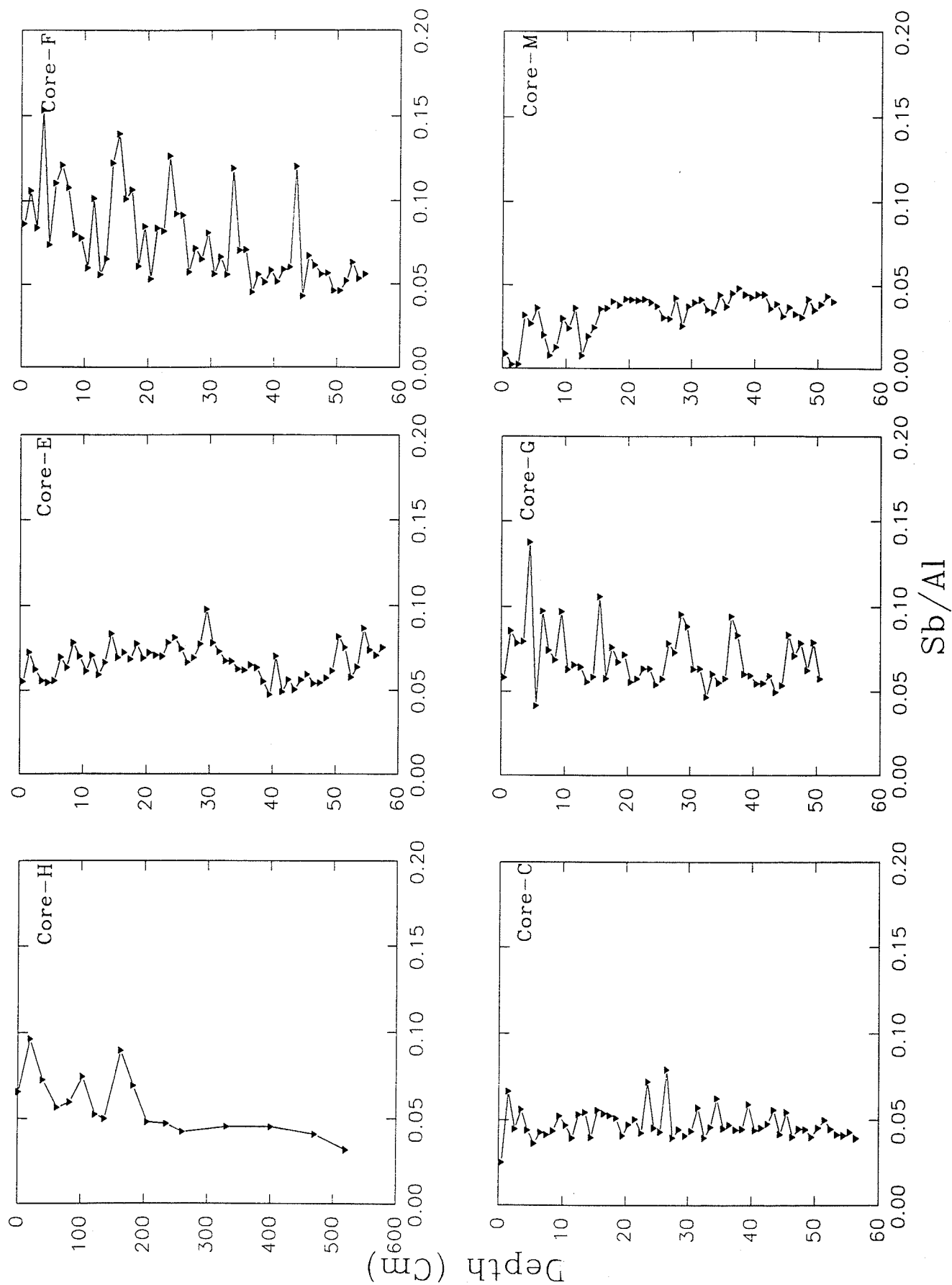
Figure 32.   Sb/Al (x10^4) versus Depth in Sediments
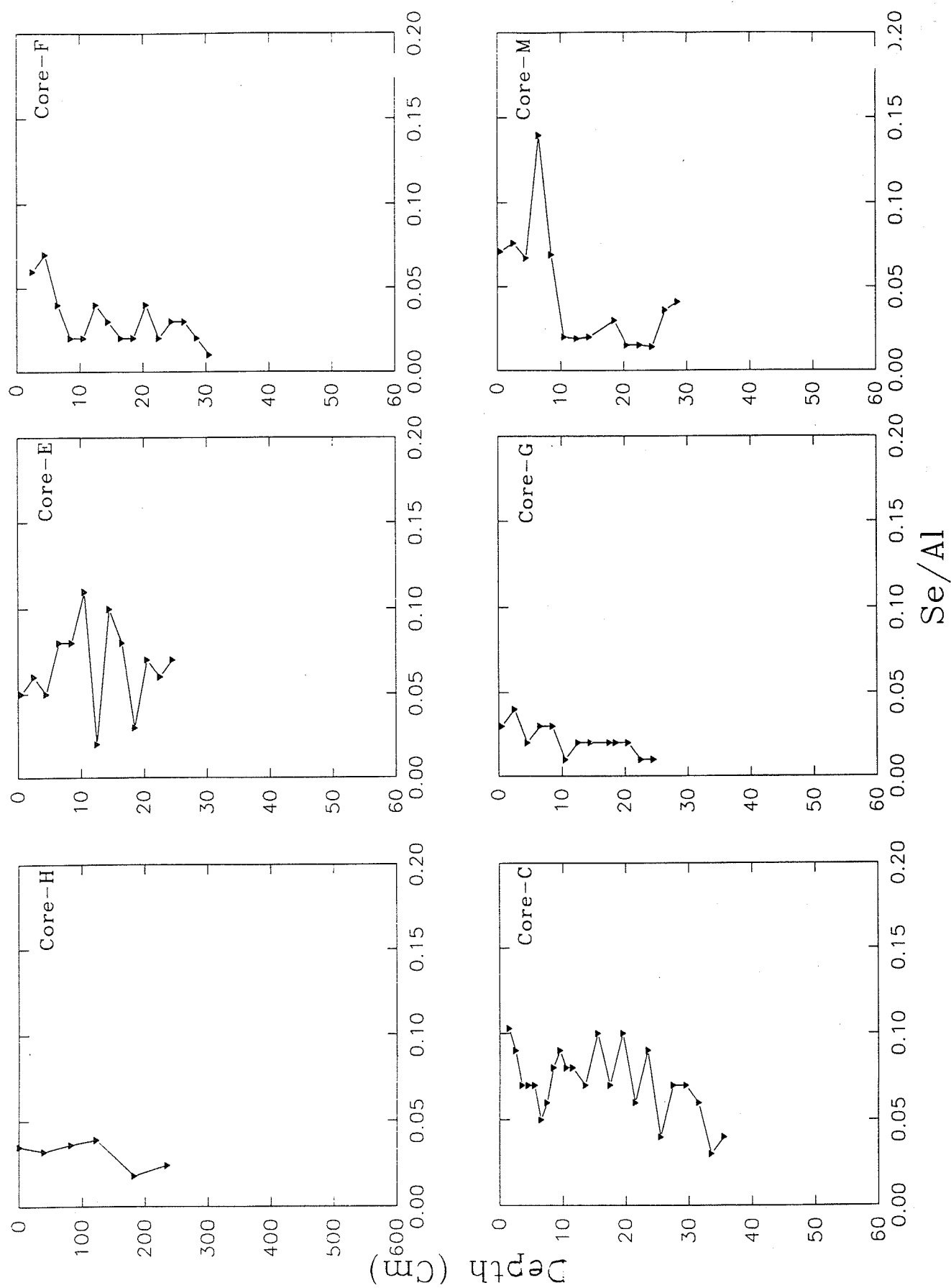
Figure 33. Se/Al (x10^4) versus Depth in Sediments
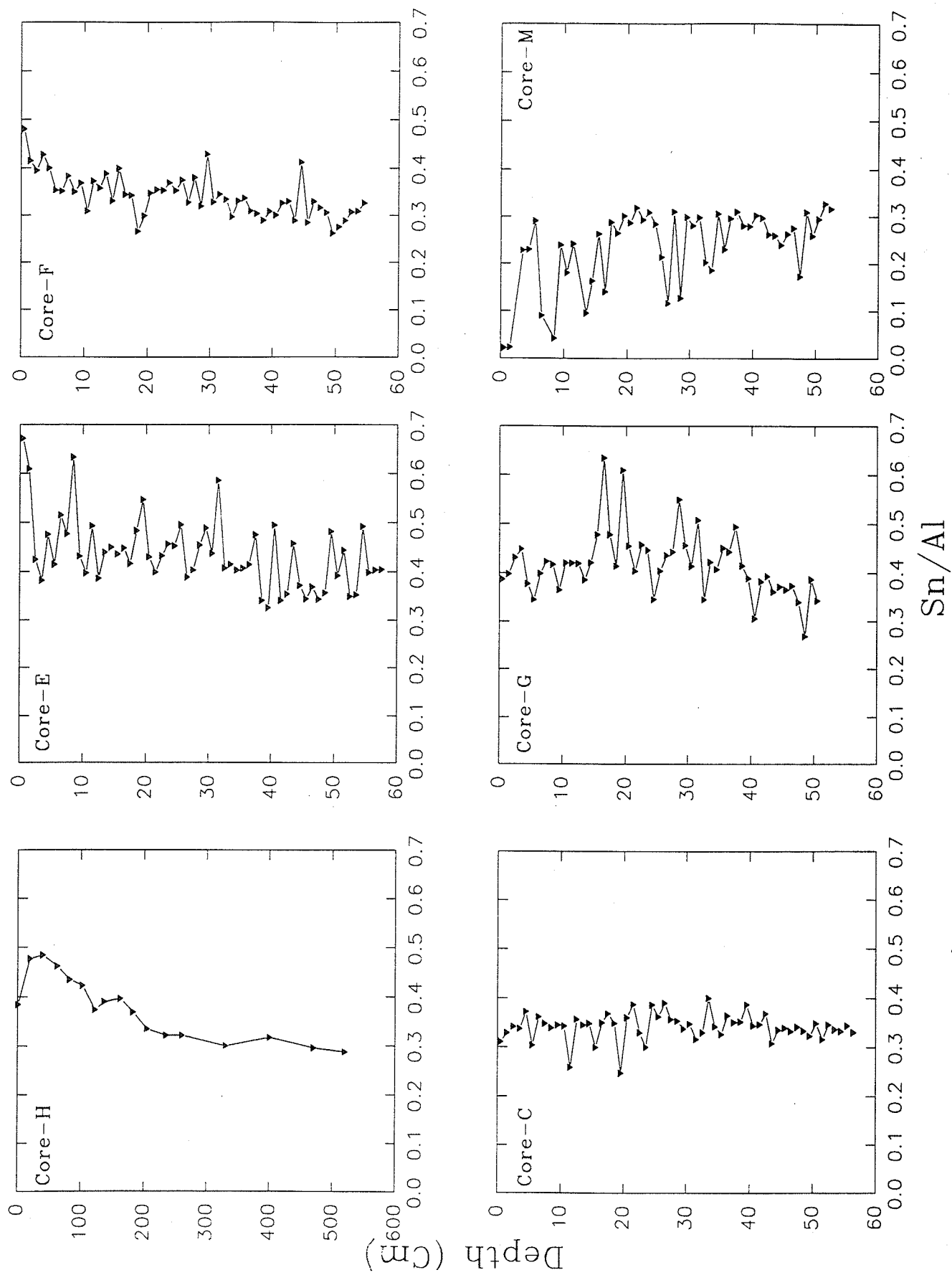
Figure. 34   Sn/Al (x10^4) versus Depth in Sediments
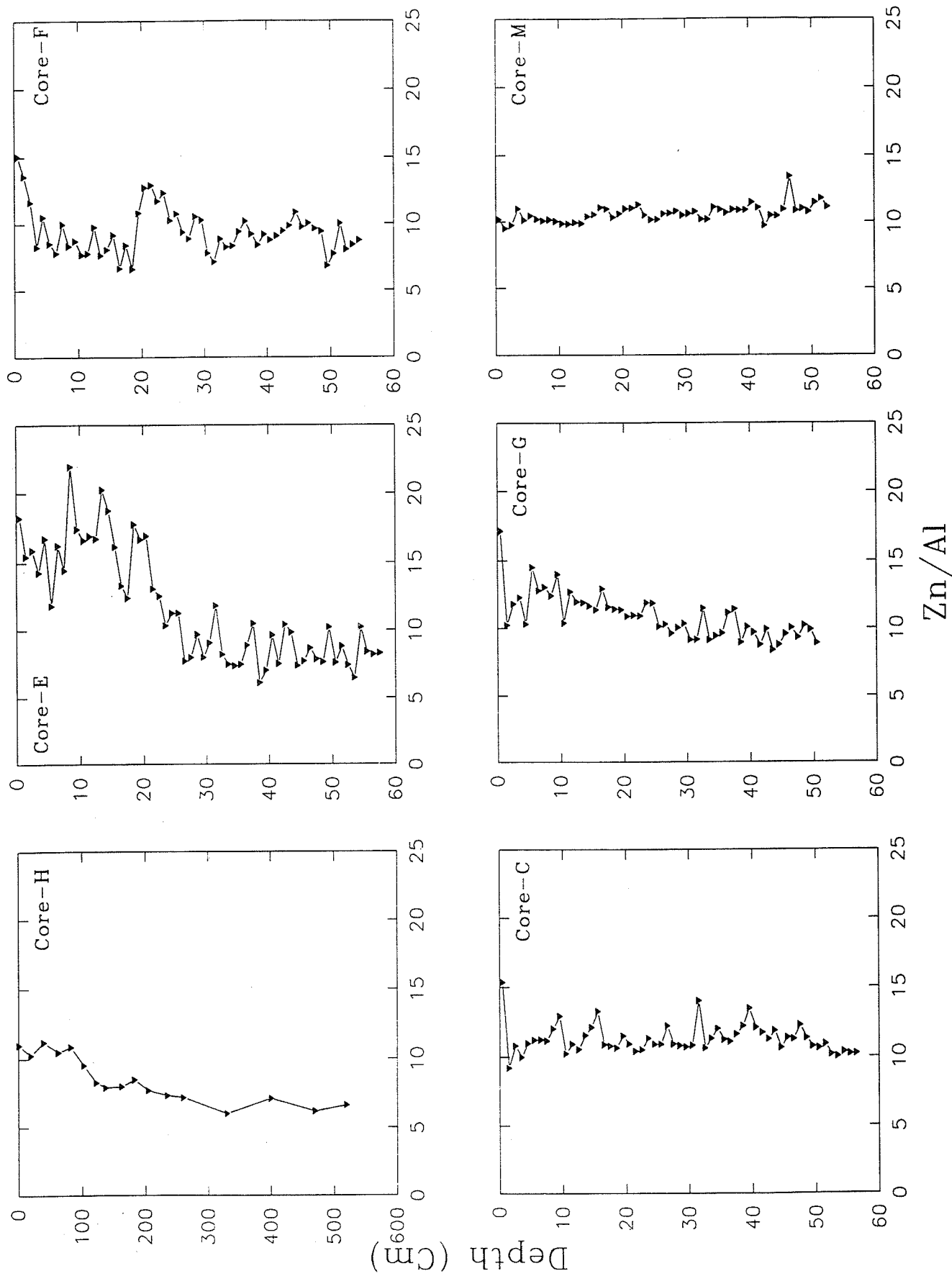
Figure 35. Zn/Al (x10⁴) versus Depth in Sediments

Figure 36: Total PAH in Core E

Concentration (ng/gdw)
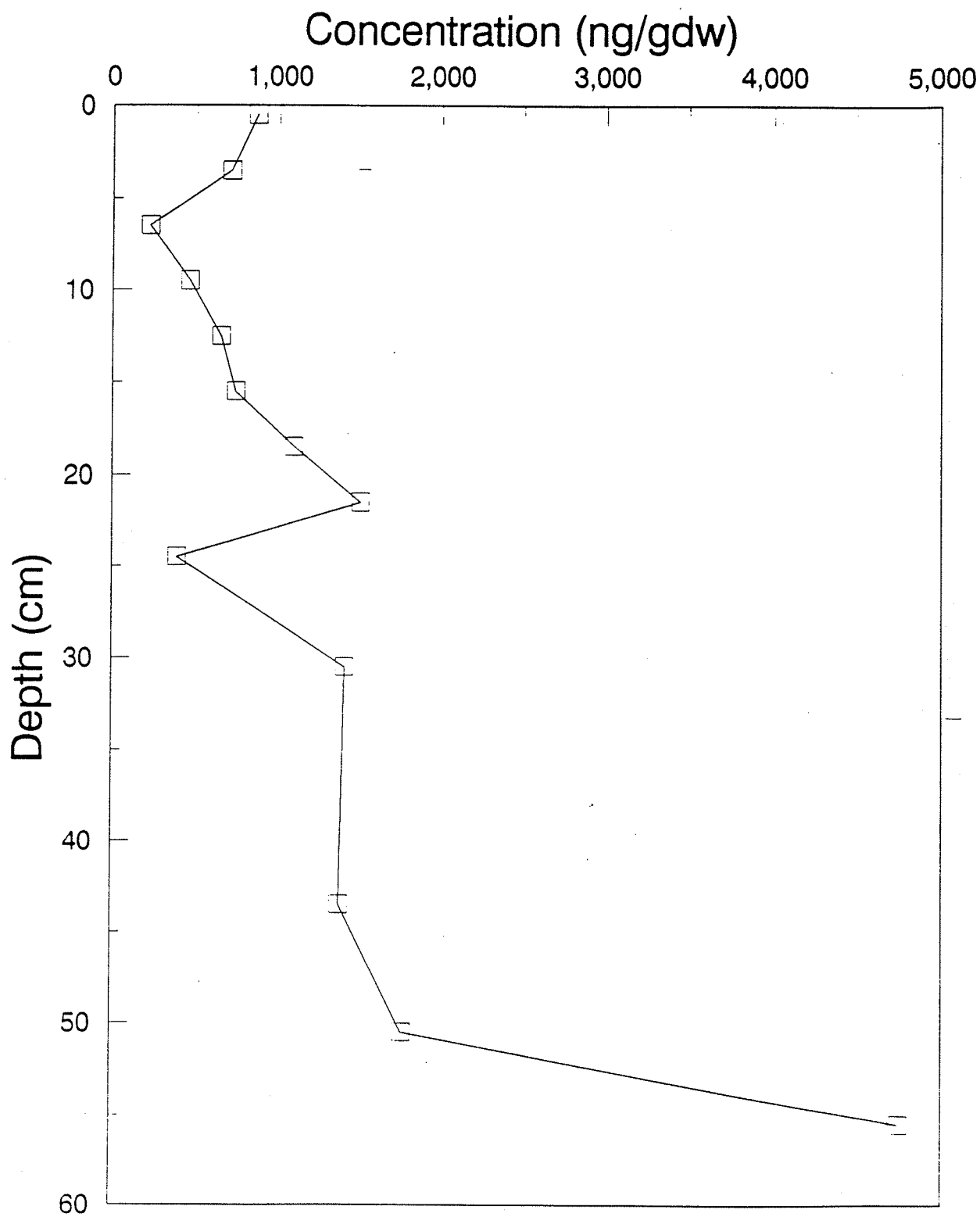
Figure 37: Individual PAH in Core E
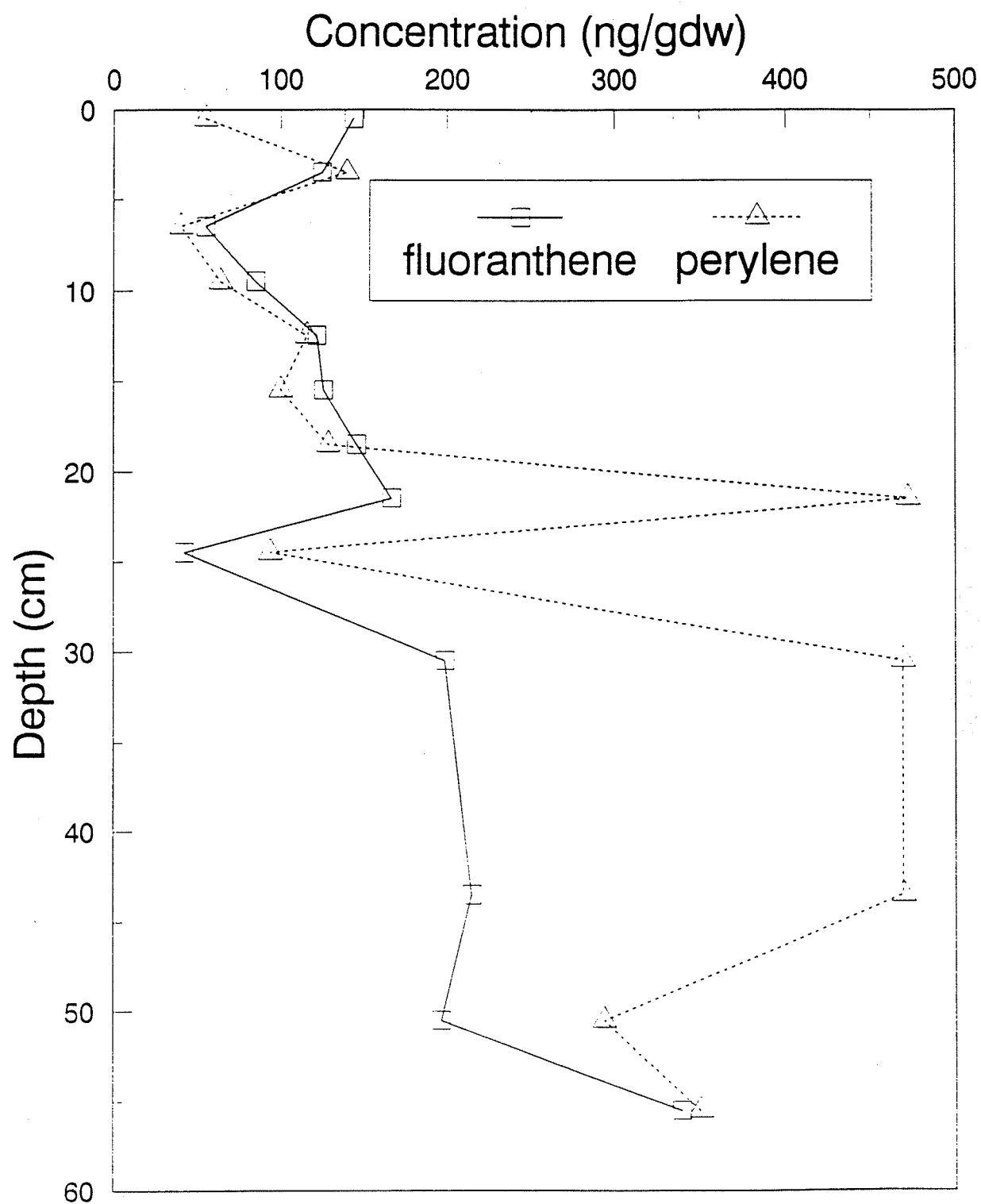
Figure 38: Total PAH in Core F
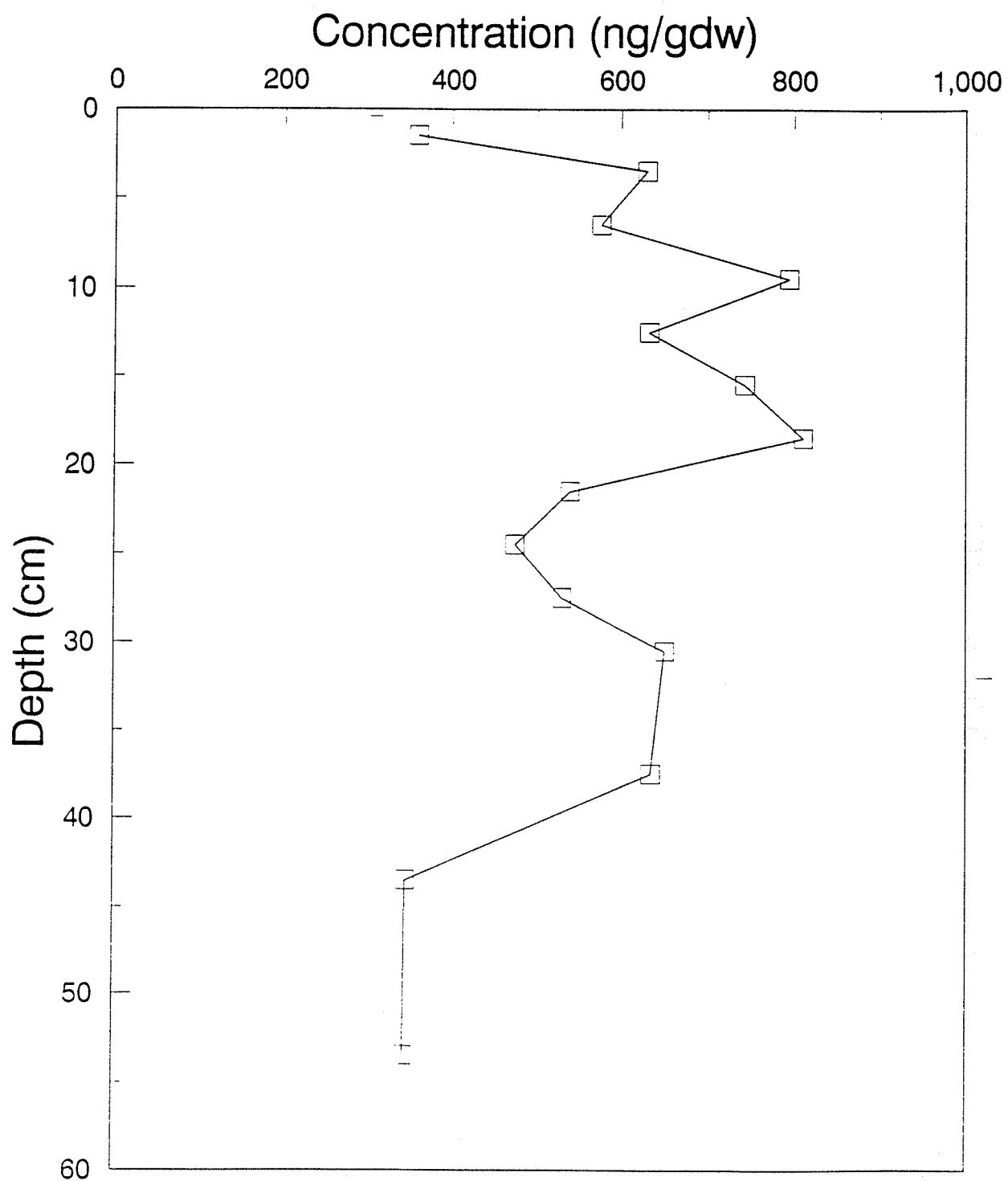
Figure 39: Individual PAH in Core F
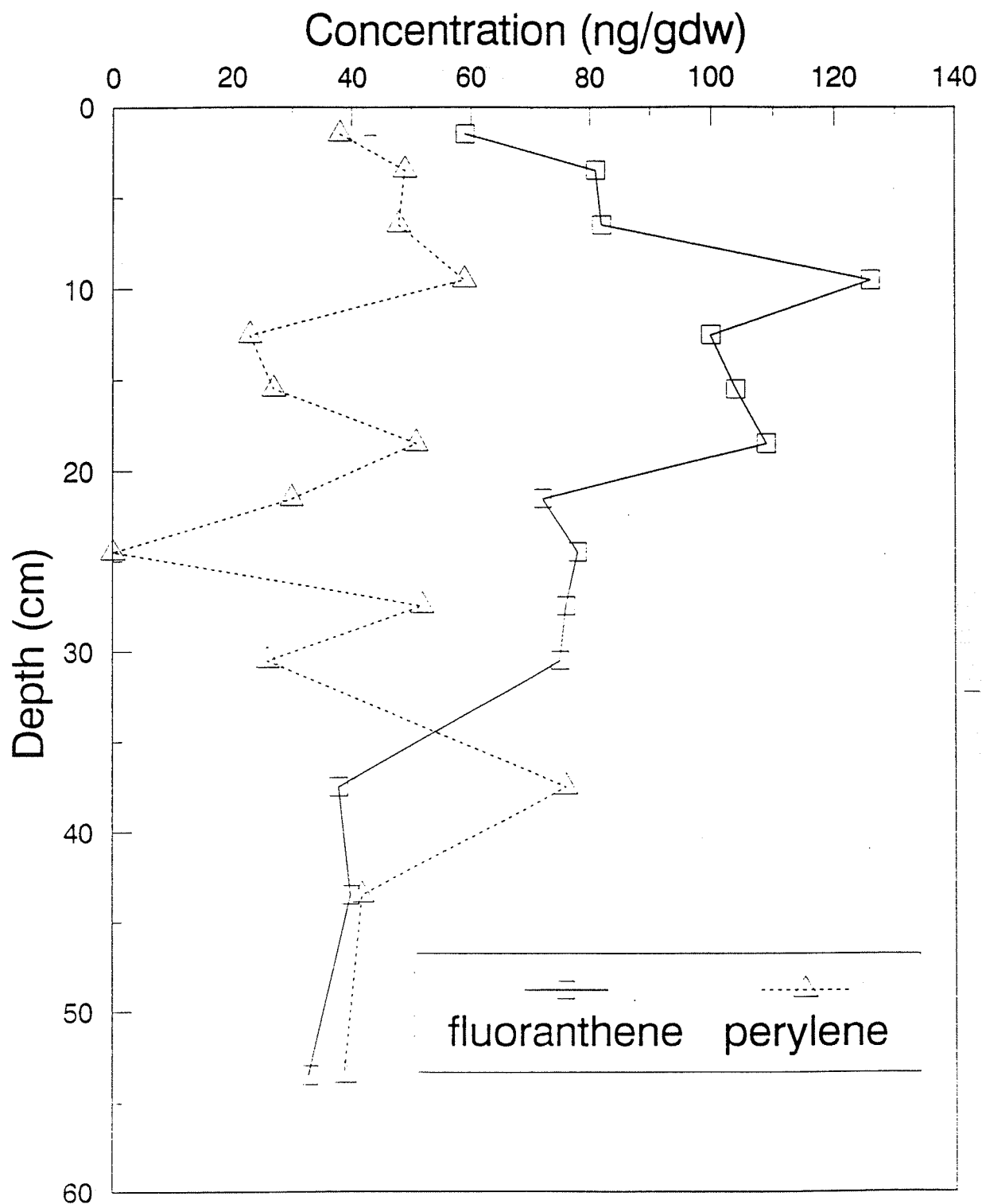
Figure 40: Total PAH in Core H
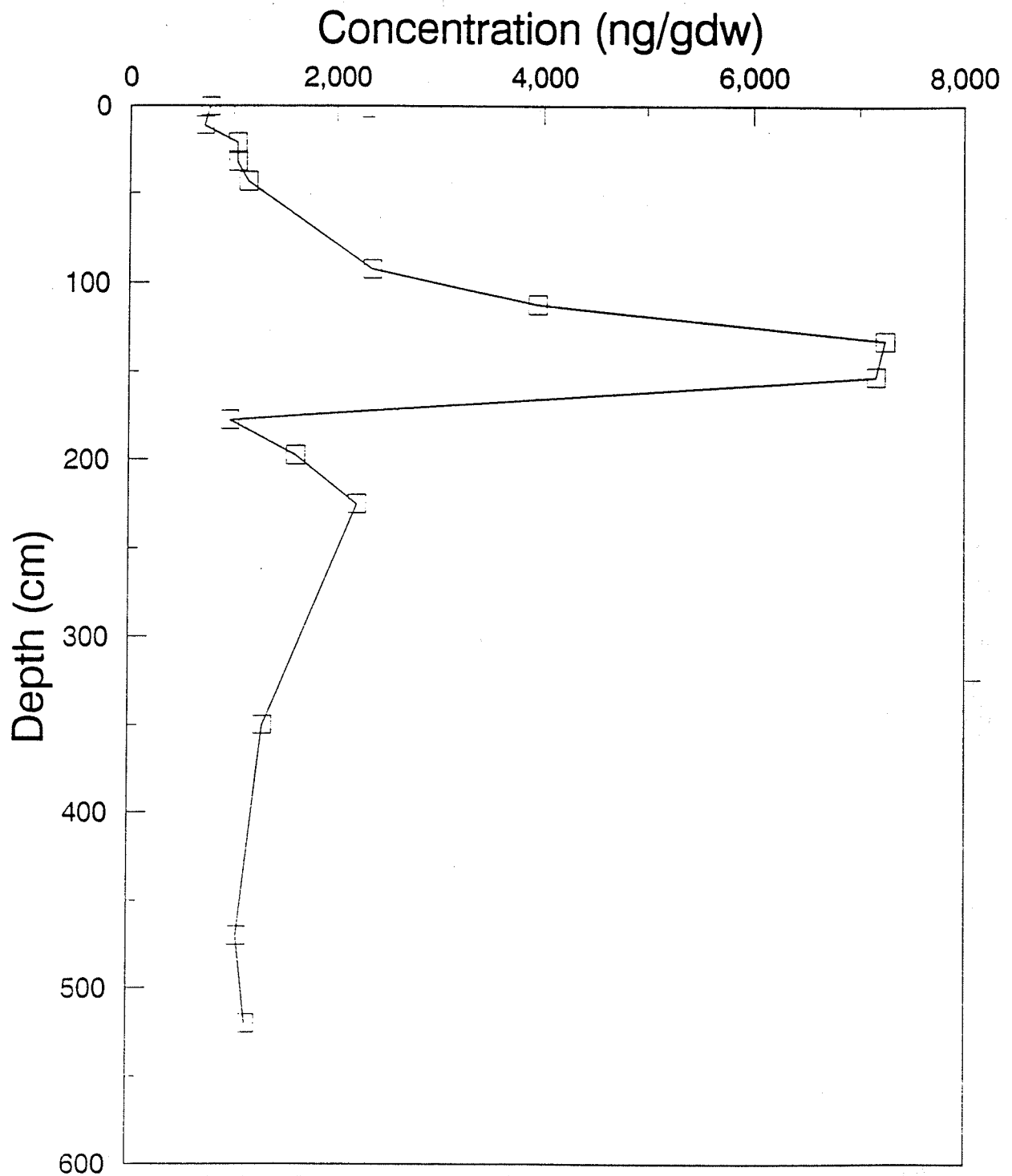
Figure 41: Individual PAH in Core H
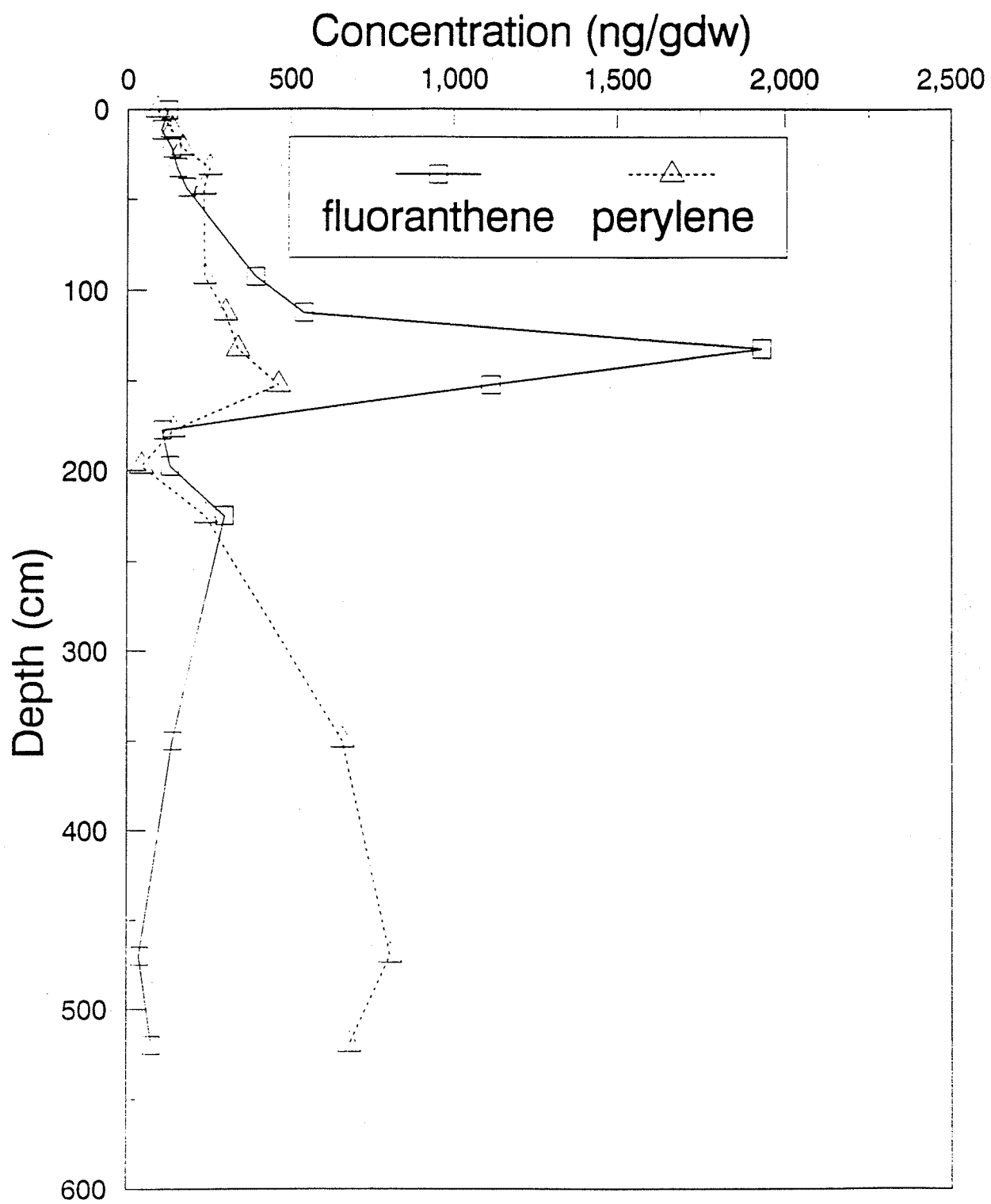
Figure 42: Total PCB in Core E
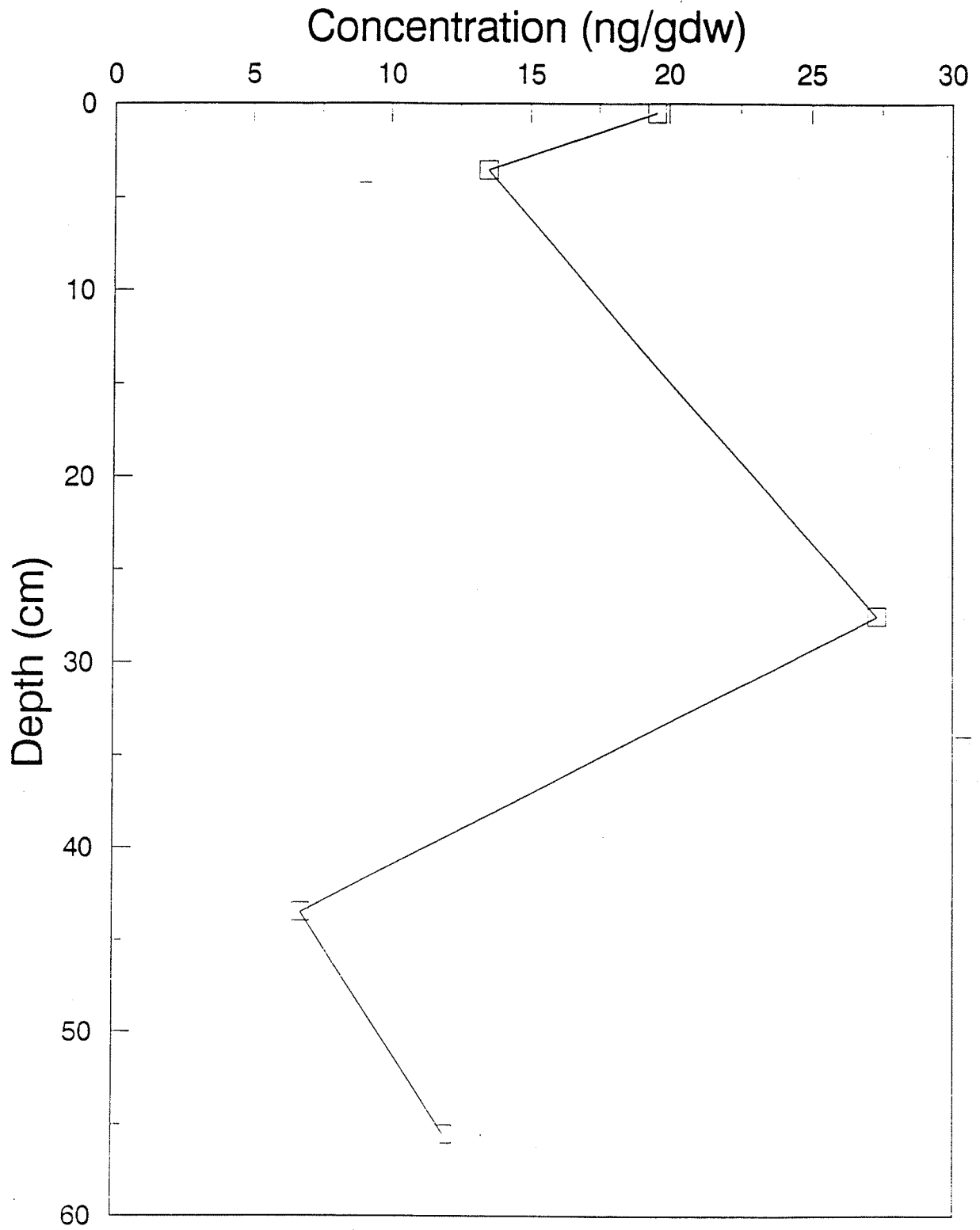
Figure 43: Total PCB in Core E
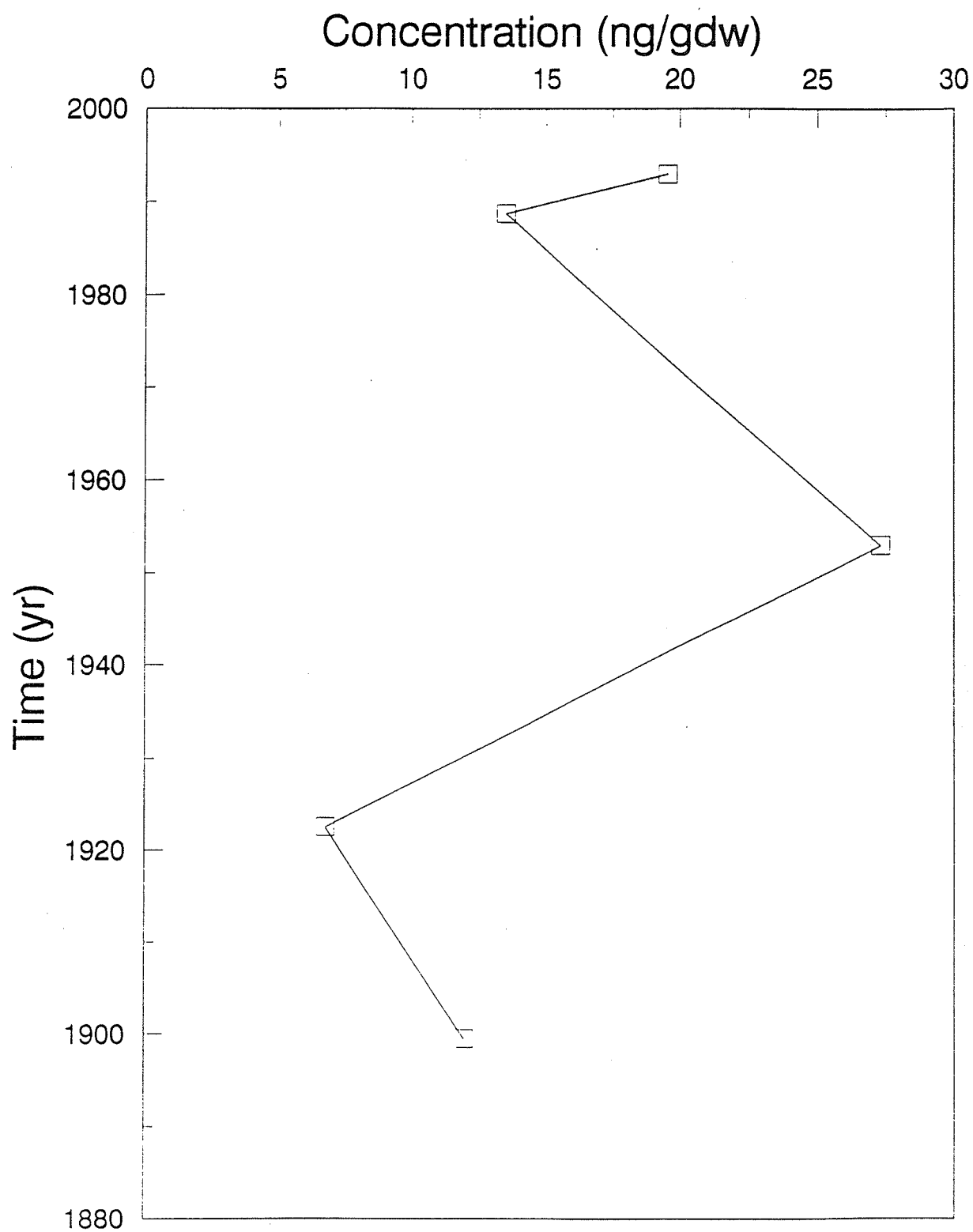
Figure 44: Individual PCB in Core E
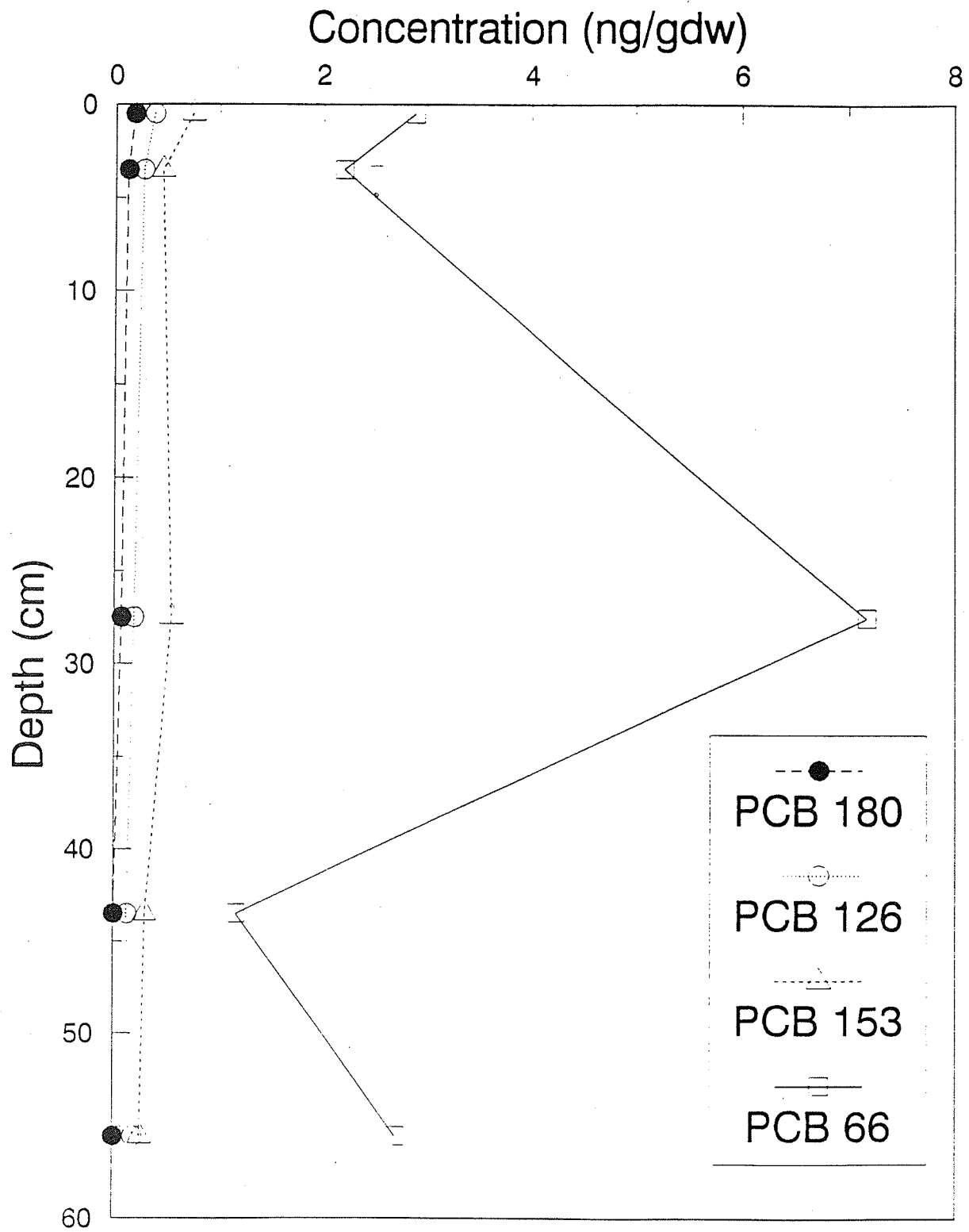
Figure 45: Total PCB in Core F
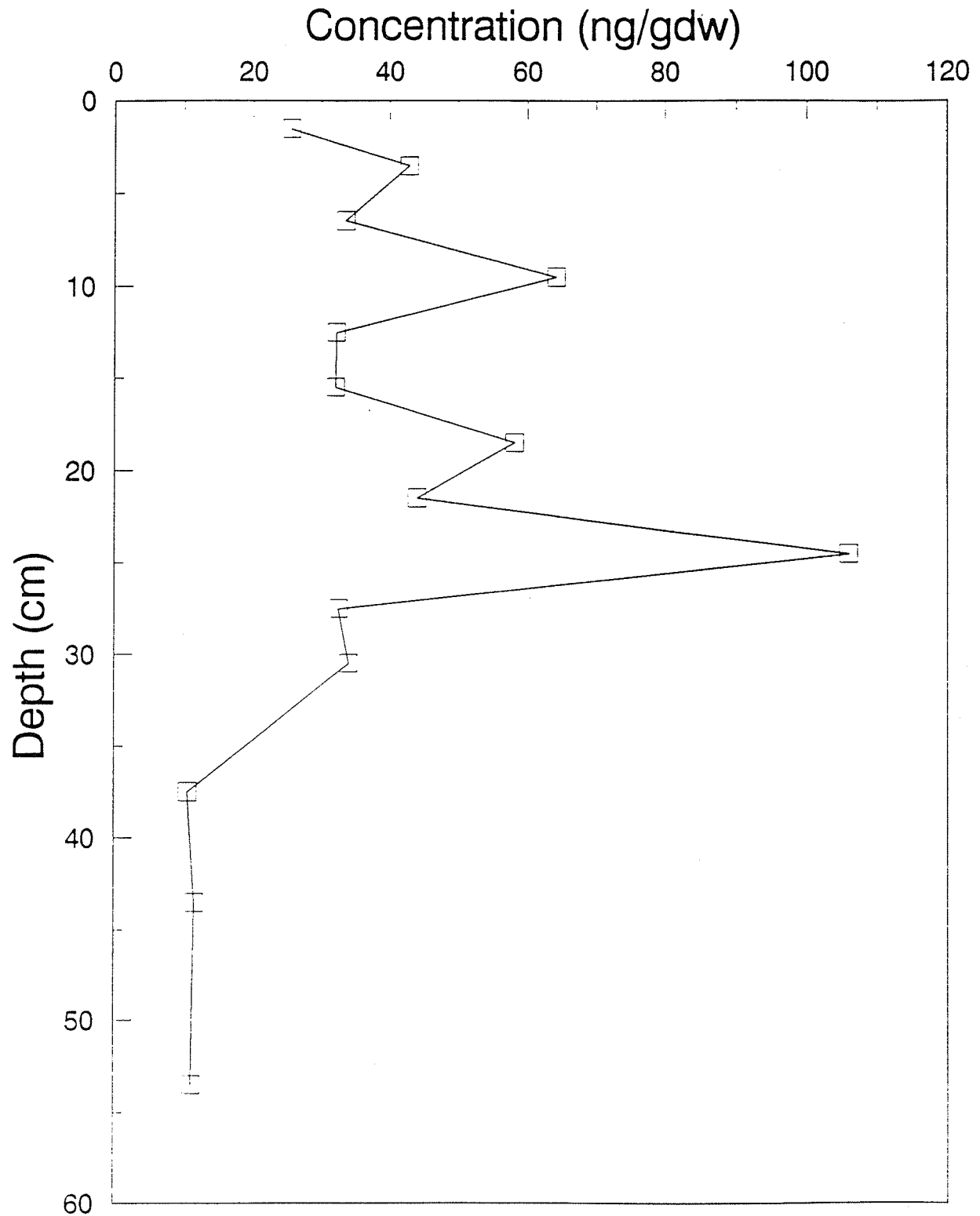
Figure 46: Total PCB in Core F
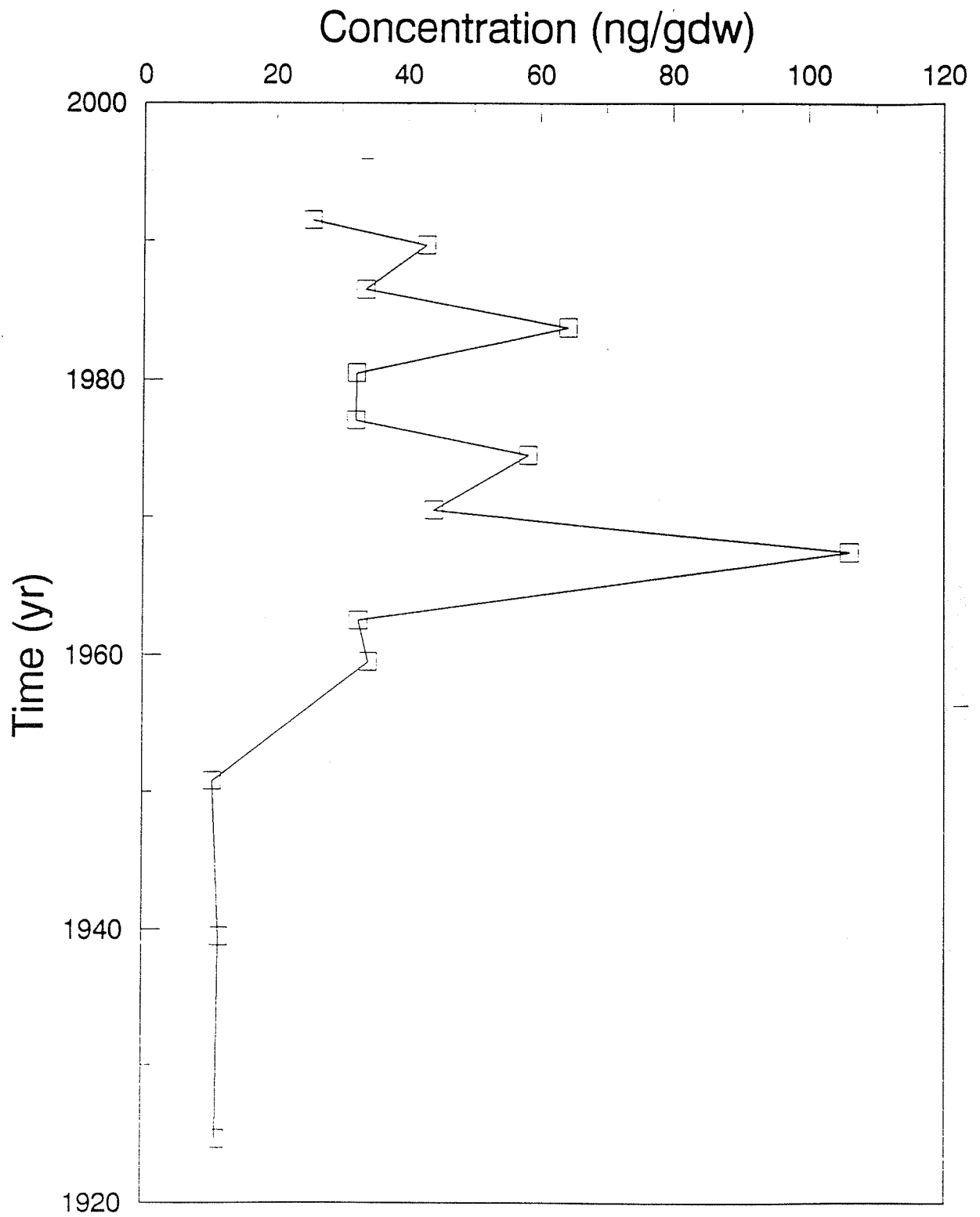
Figure 47: Individual PCB in Core F
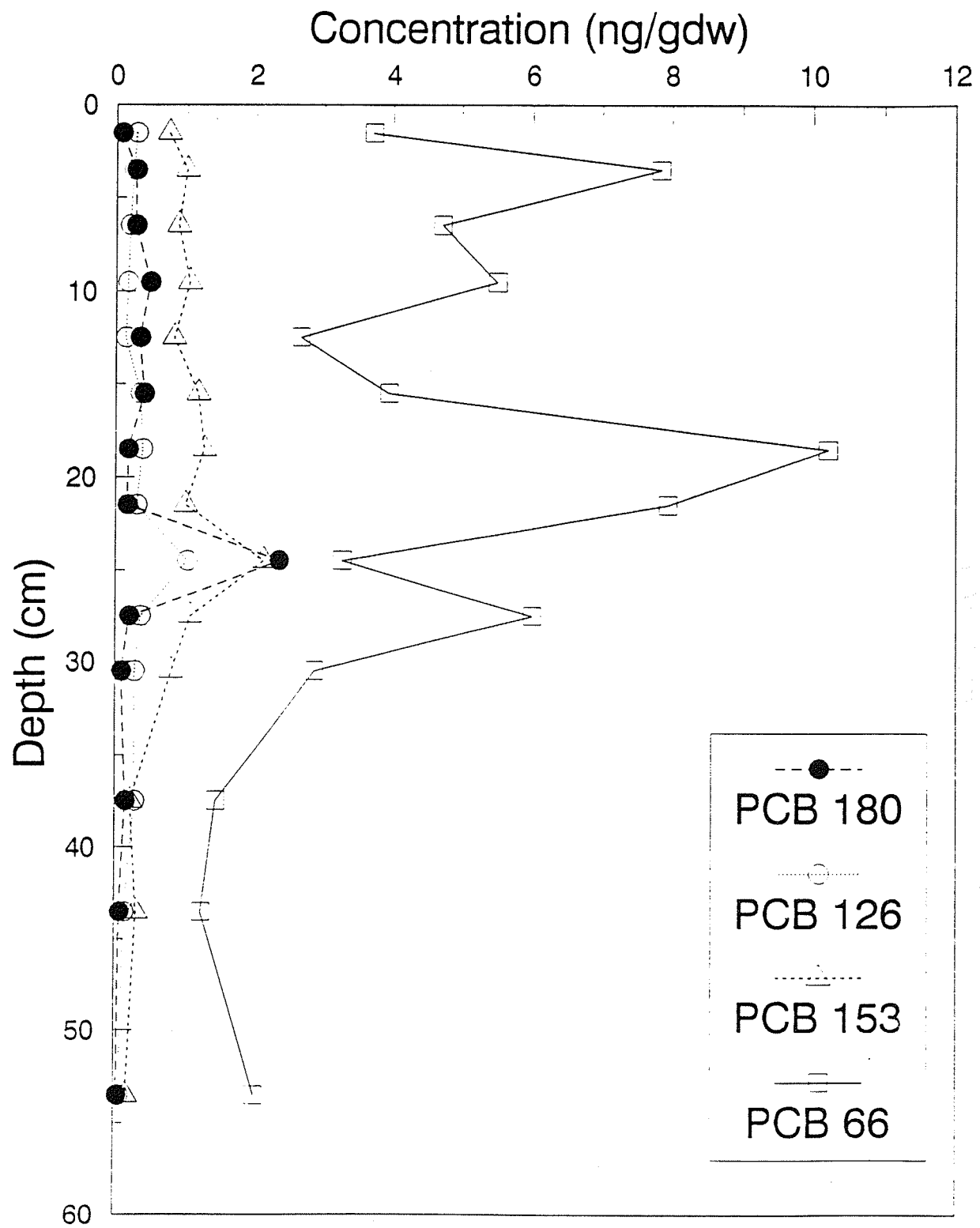
Figure 48: Total PCB in Core H
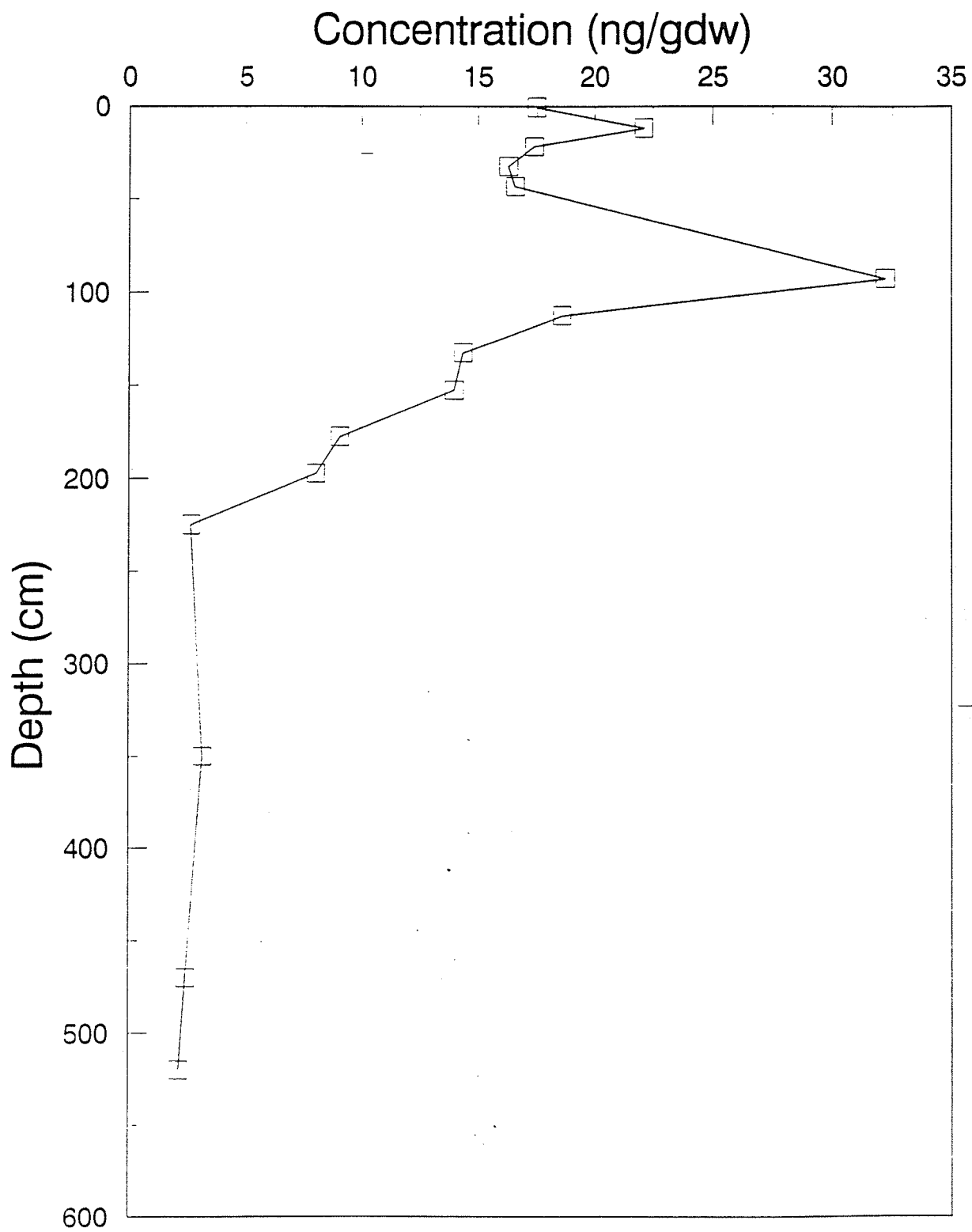
Figure 49: Total PCB in Core H
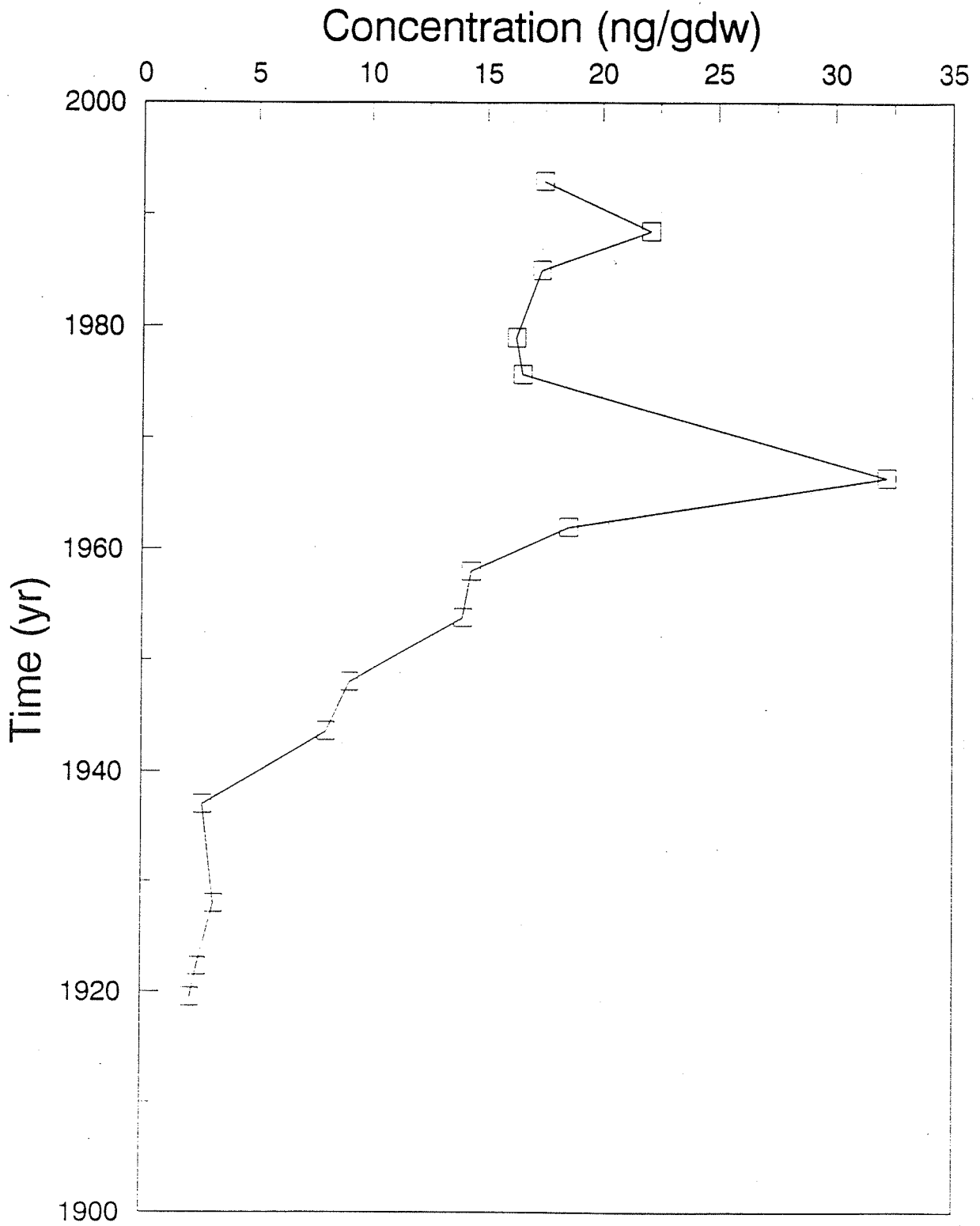
Figure 50: Individual PCB in Core H

Concentration (ng/gdw)

Depth (cm)

Legend:
PCB 126   PCB 180
PCB 66   PCB 153
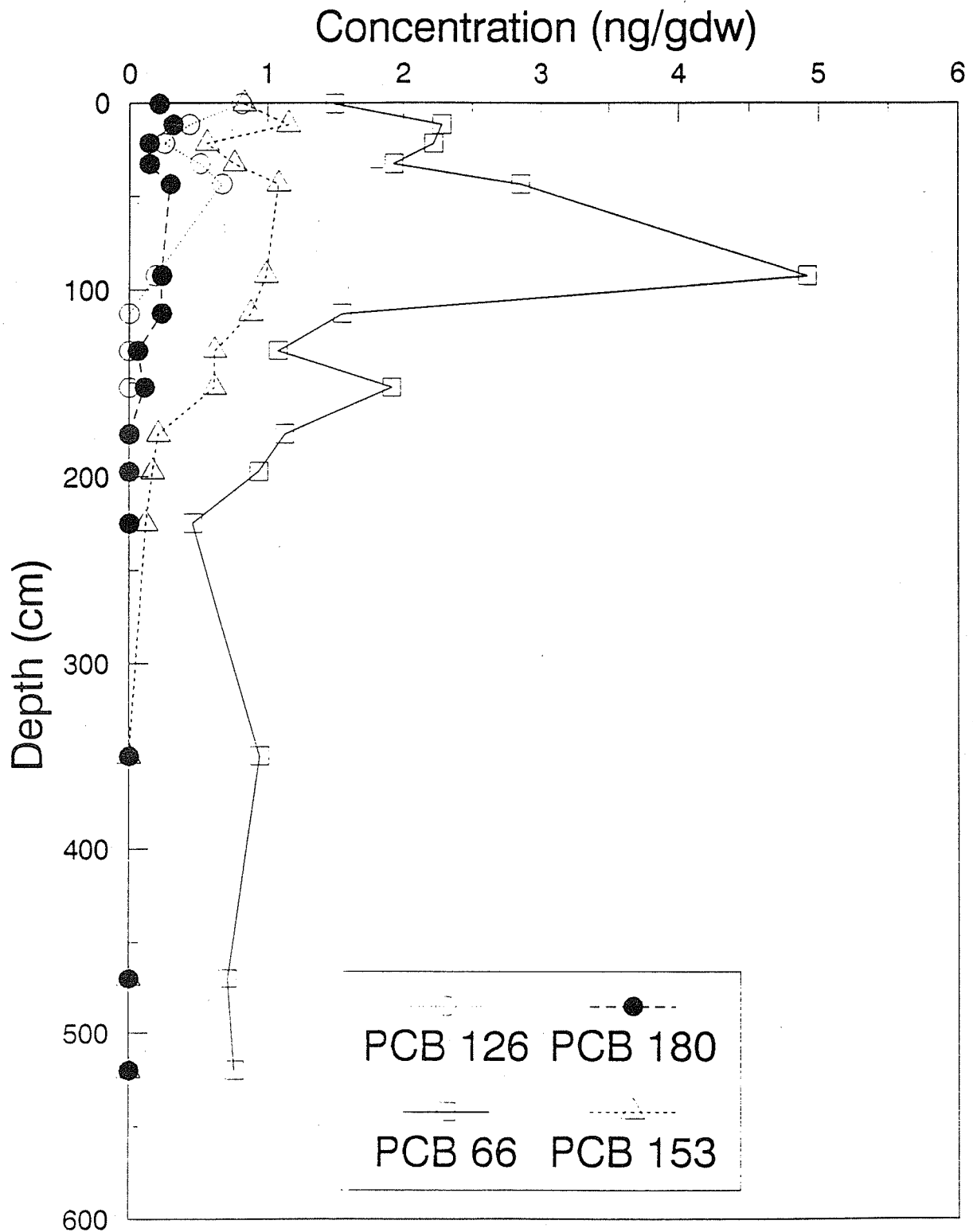
Figure 51: Total DDT in Core F
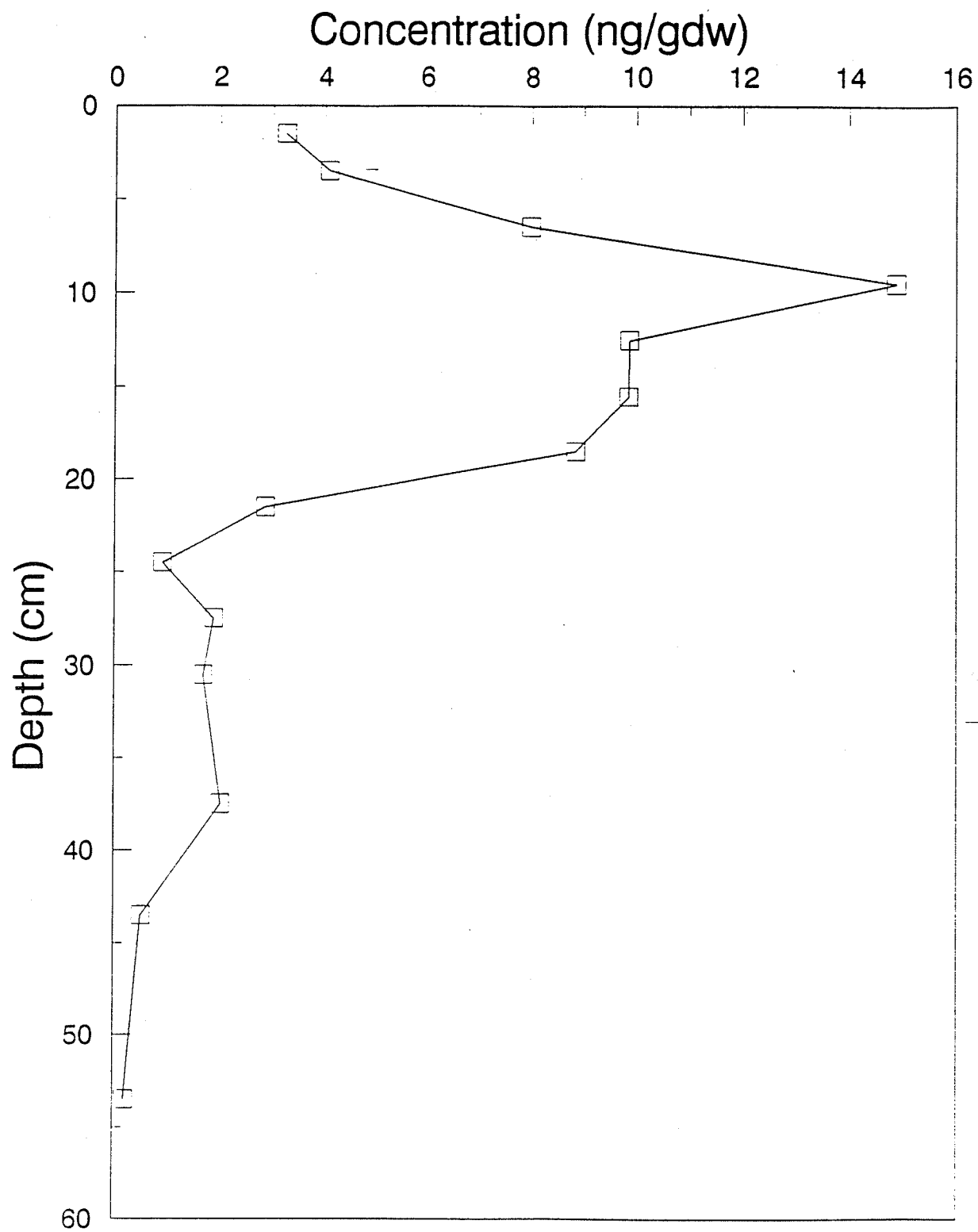
Figure 52: Individual Pesticides in Core F

Concentration (ng/gdw)

Chlordane Dieldrin
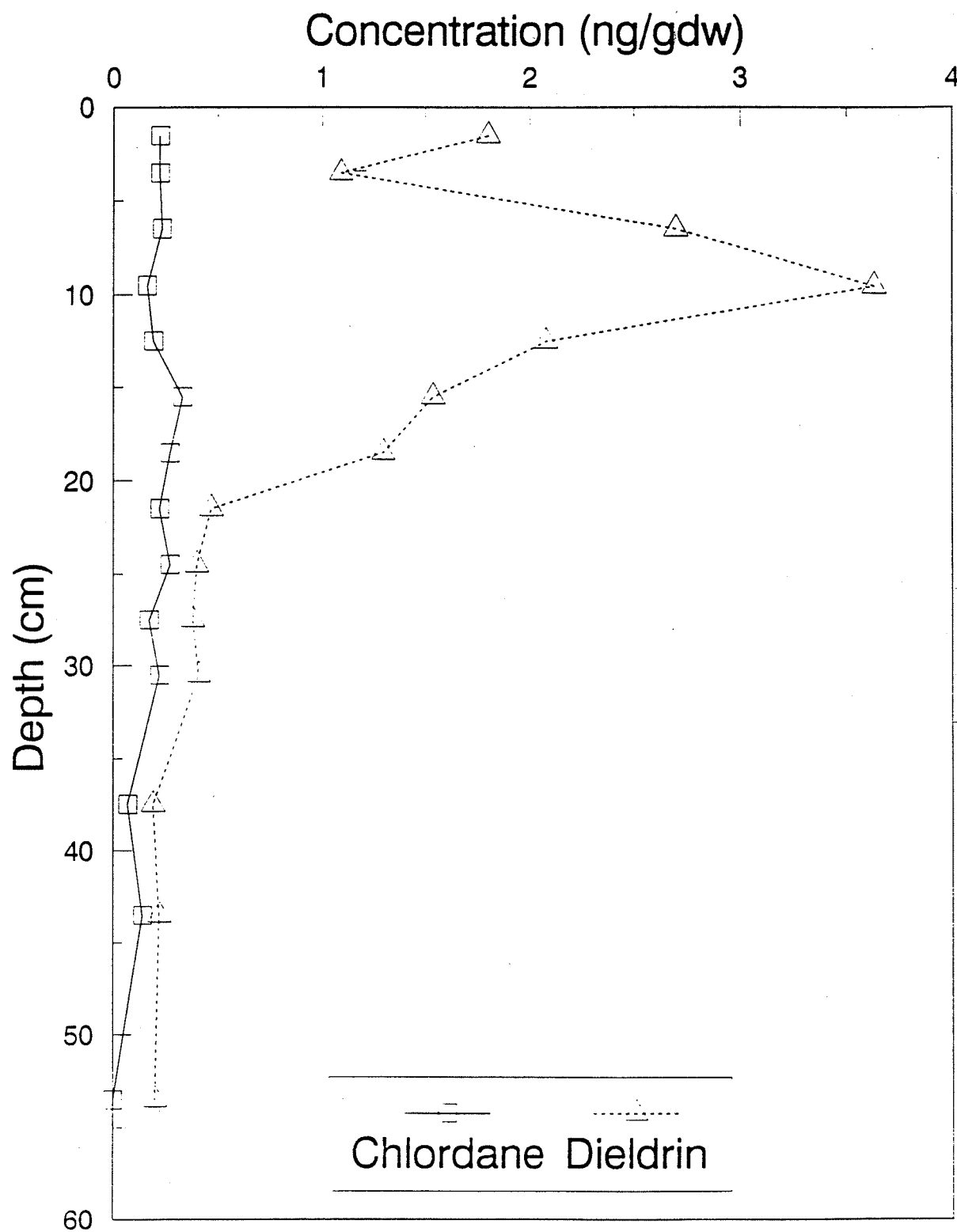
Figure 53: Individual Pesticides in Core F

4,4'-DDD 4,4'-DDE
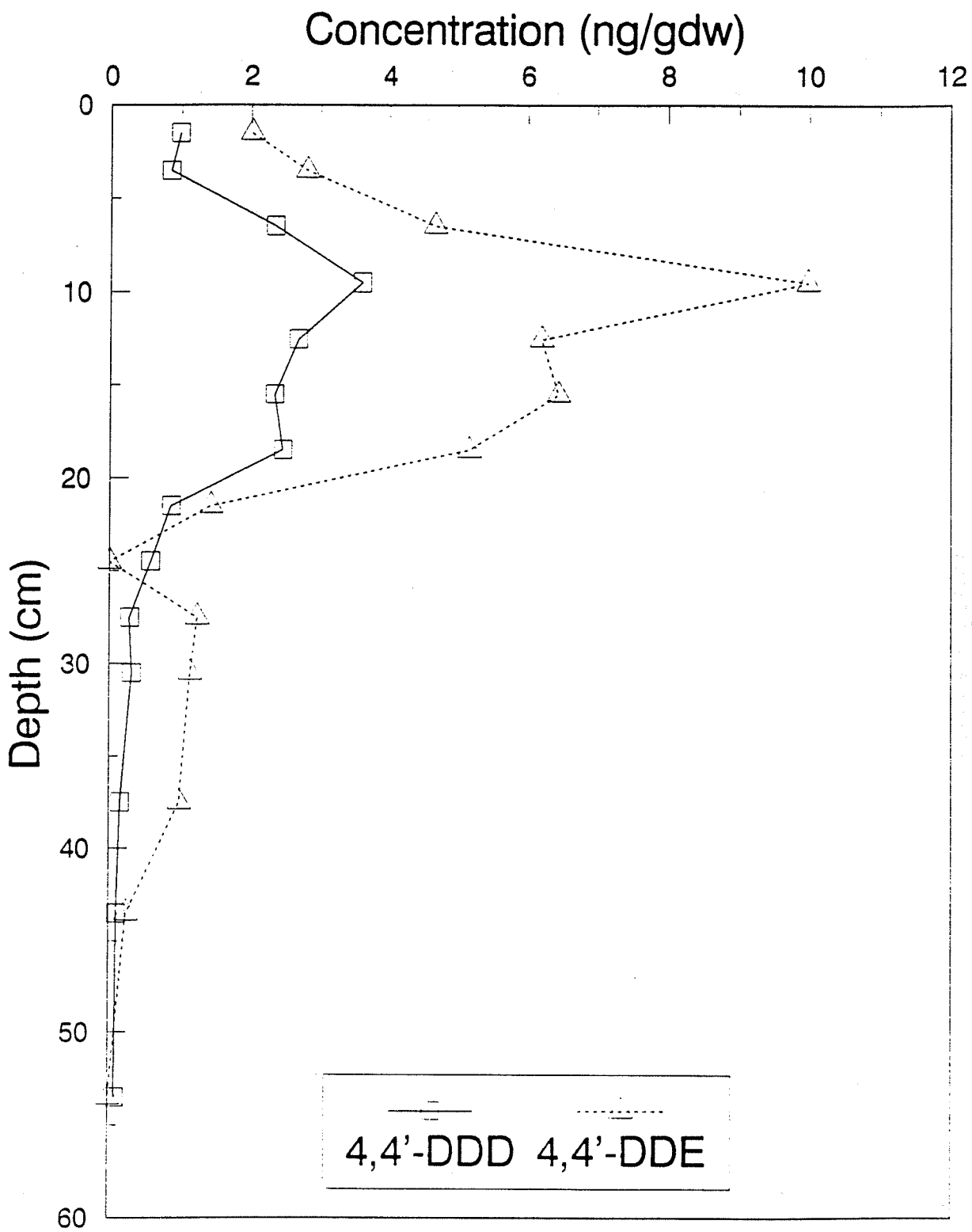
Figure 54: Total DDT in Core H
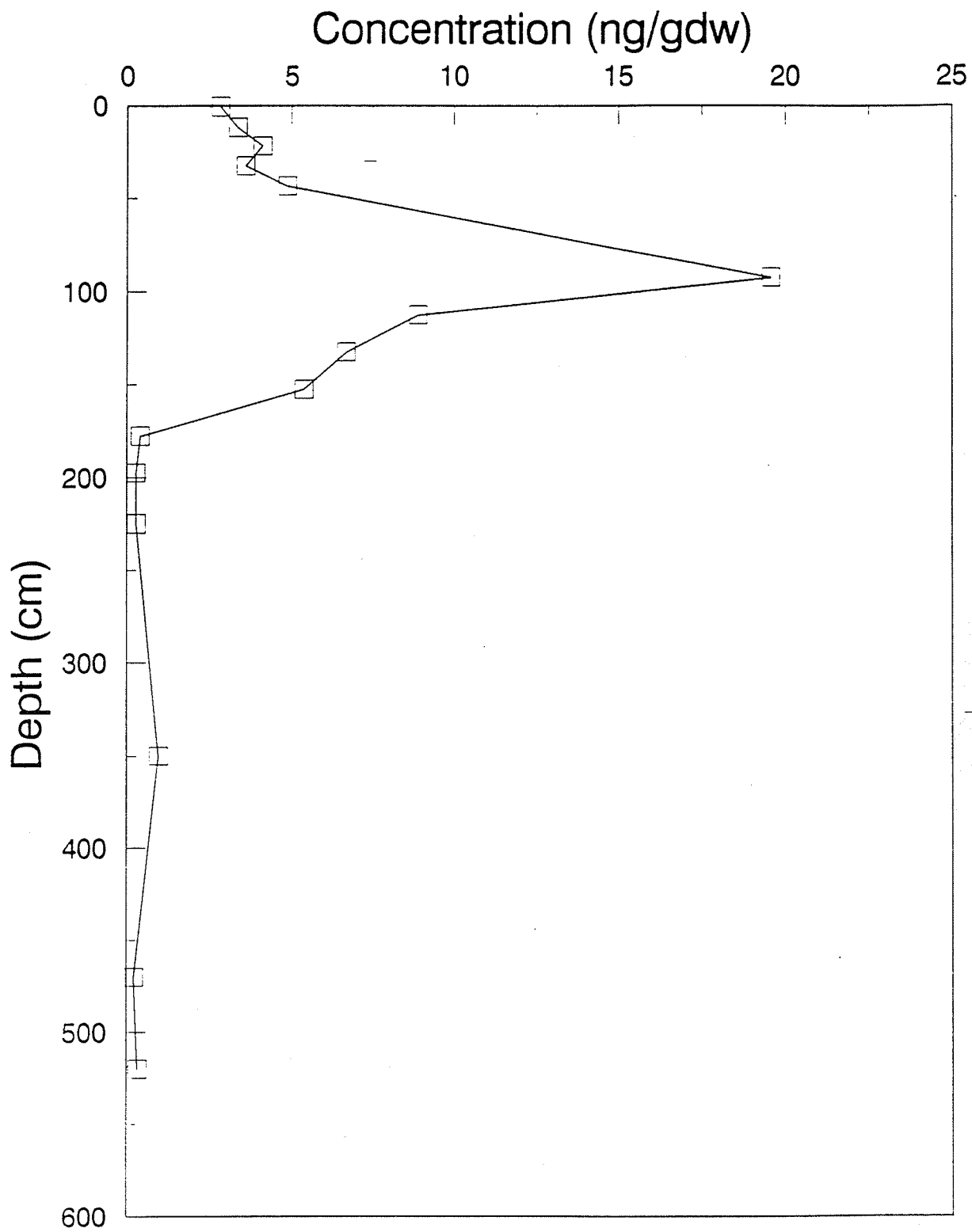
Figure 55: Individual Pesticides in Core H

Chlordane Dieldrin
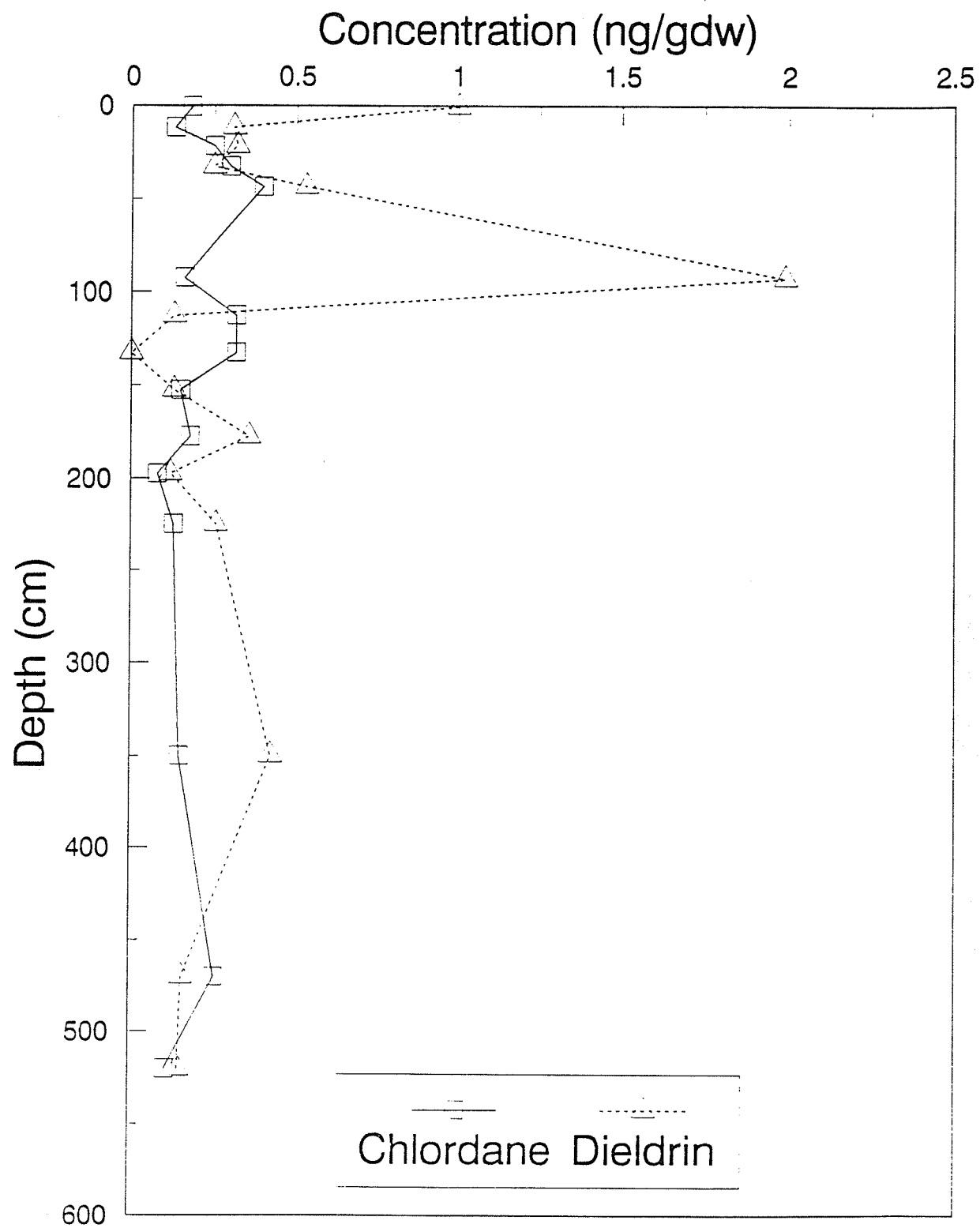
Figure 56: Individual Pesticides in Core H
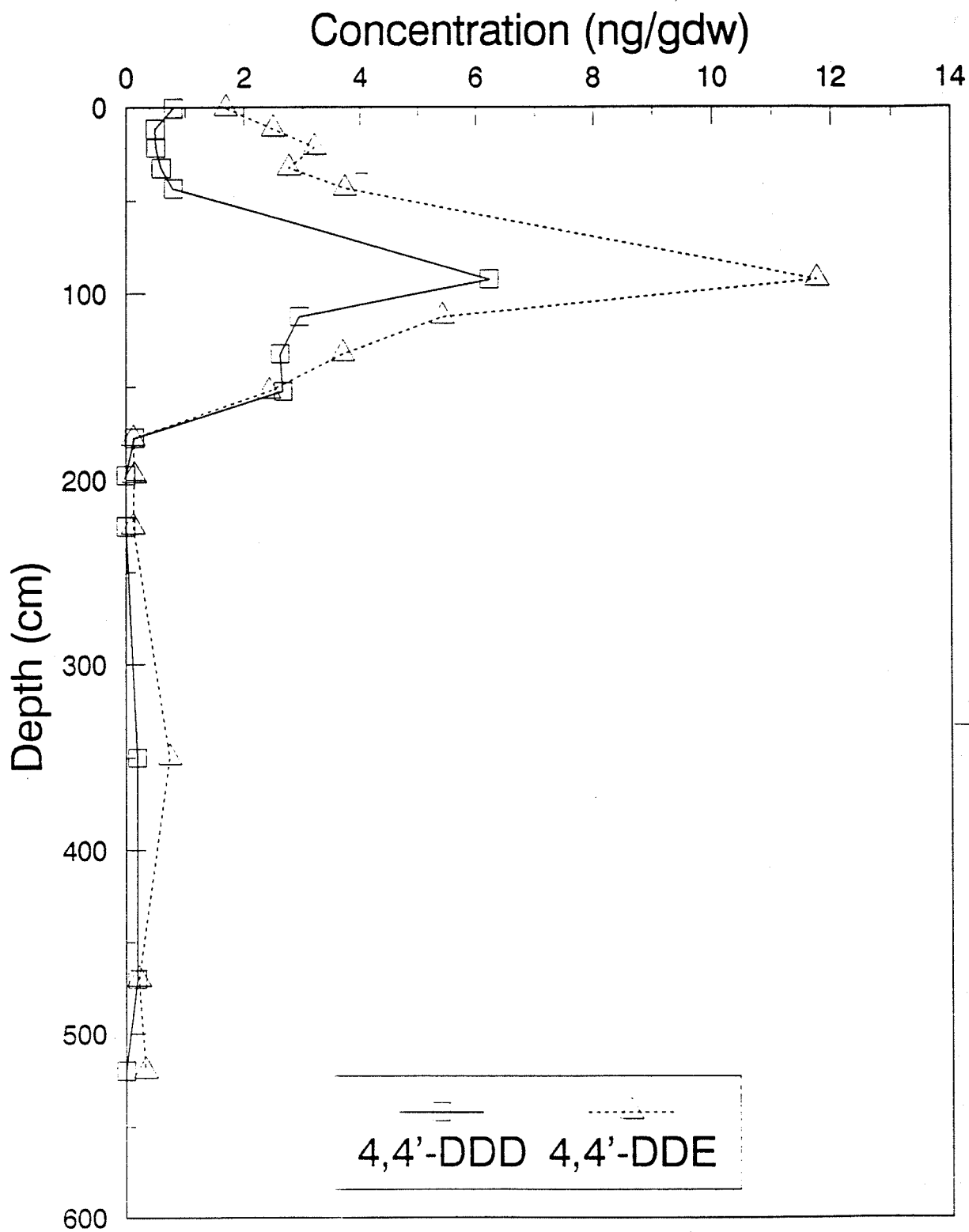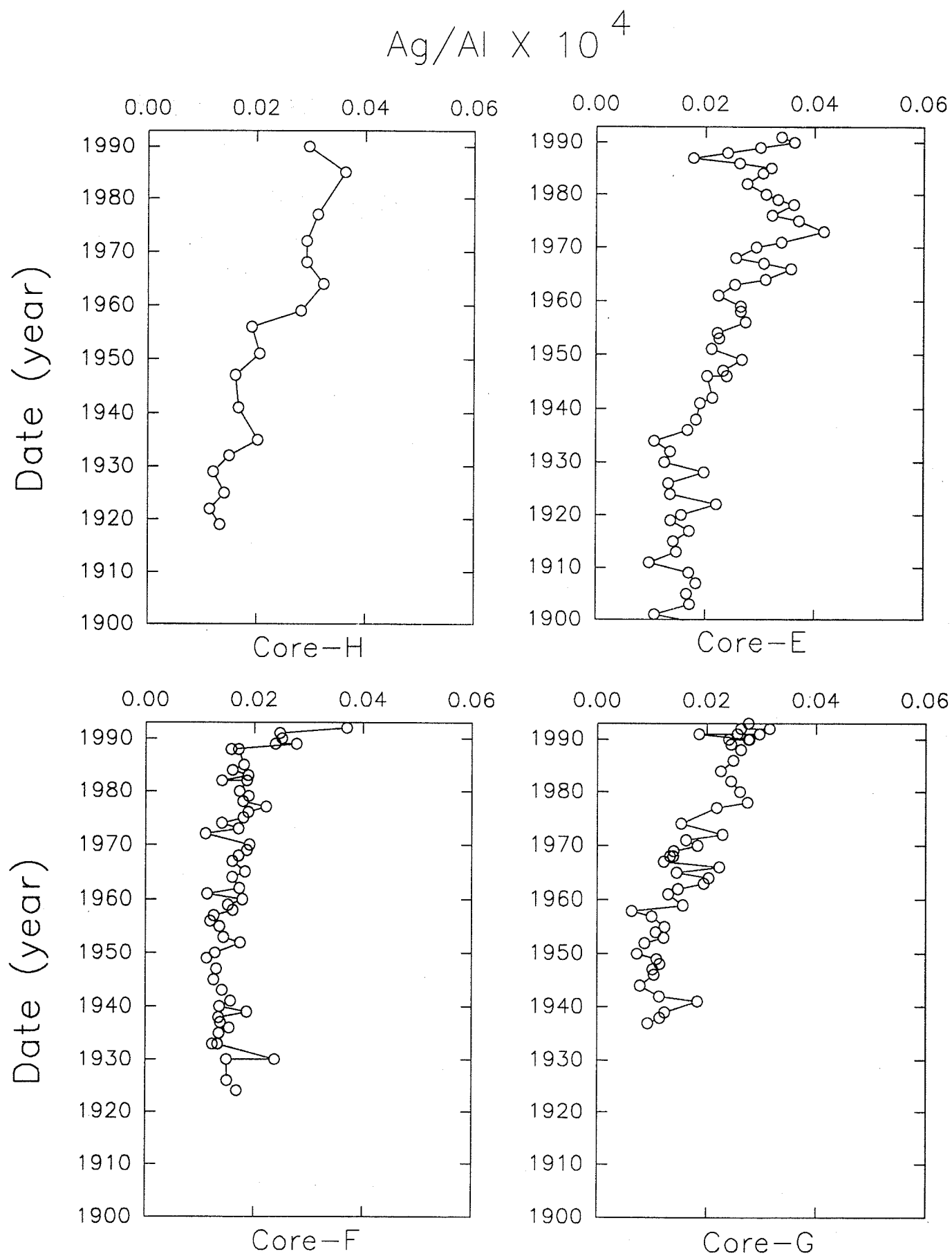
Figure 57.   Ag/Al Ratio in Sediments versus Date

Zn/Al X 10^4
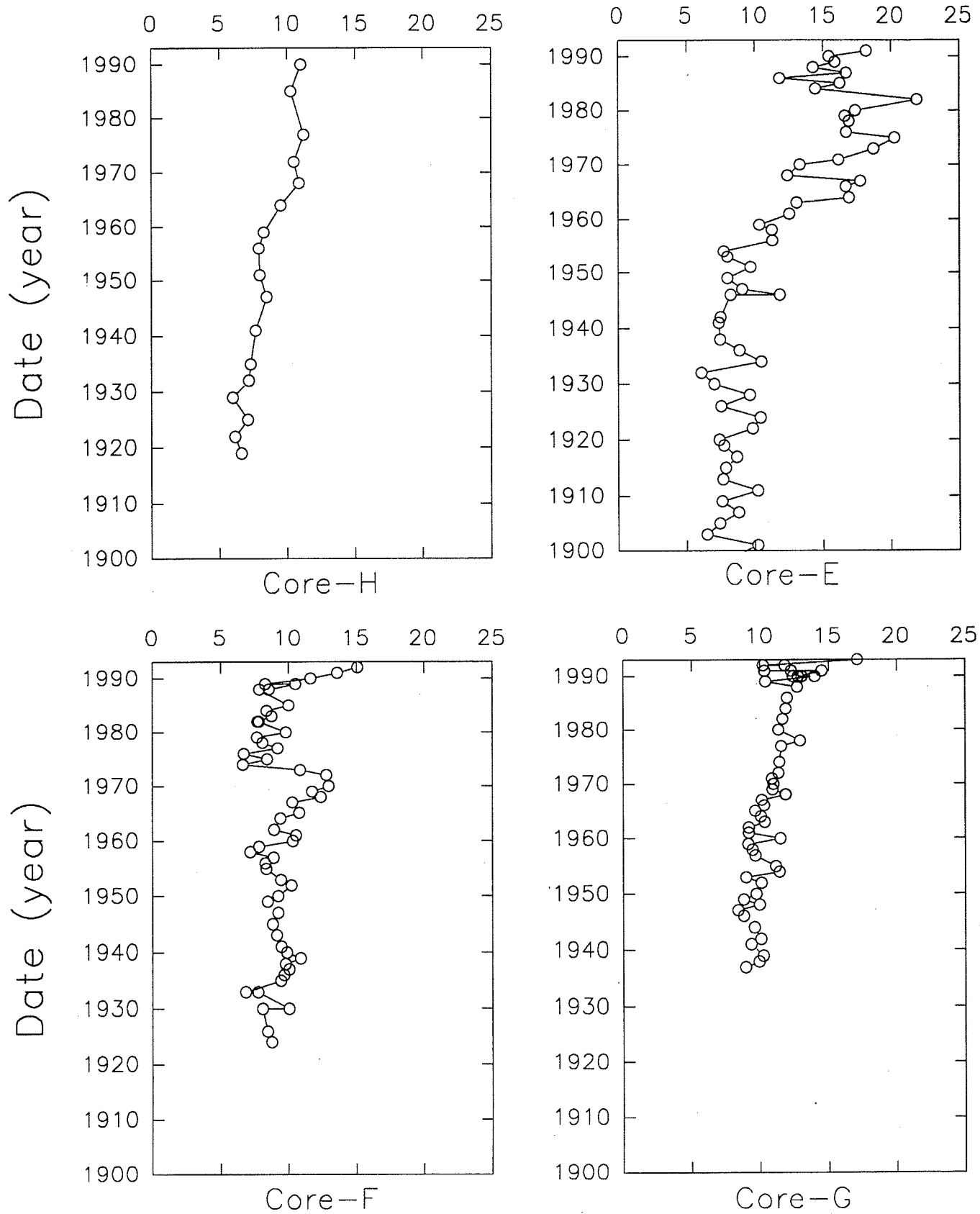
Figure 58. Zn/Al Ratio in Sediments versus Date

Cd/Al X 10^4
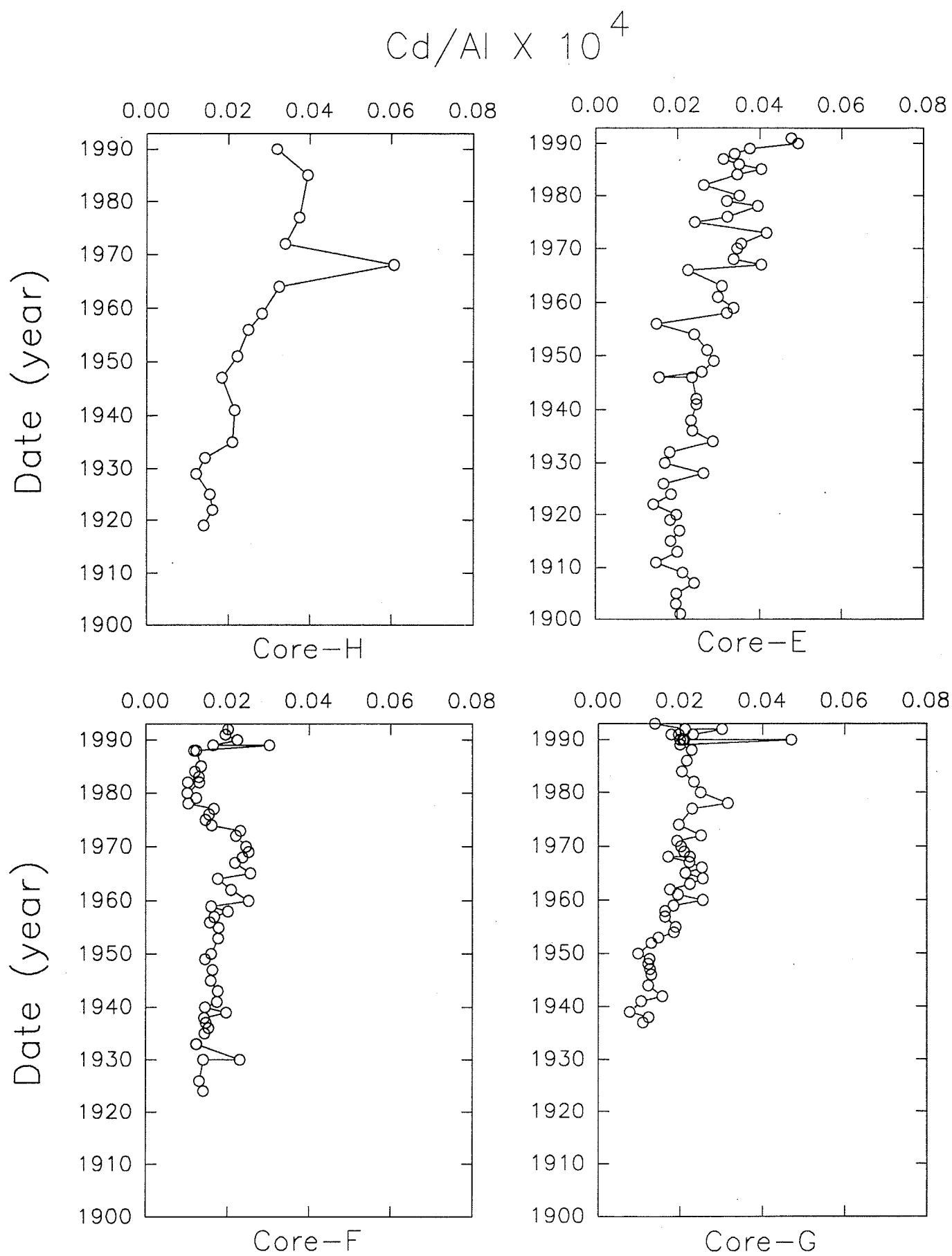
Figure 59. Cd/Al Ratio in sediments versus Date
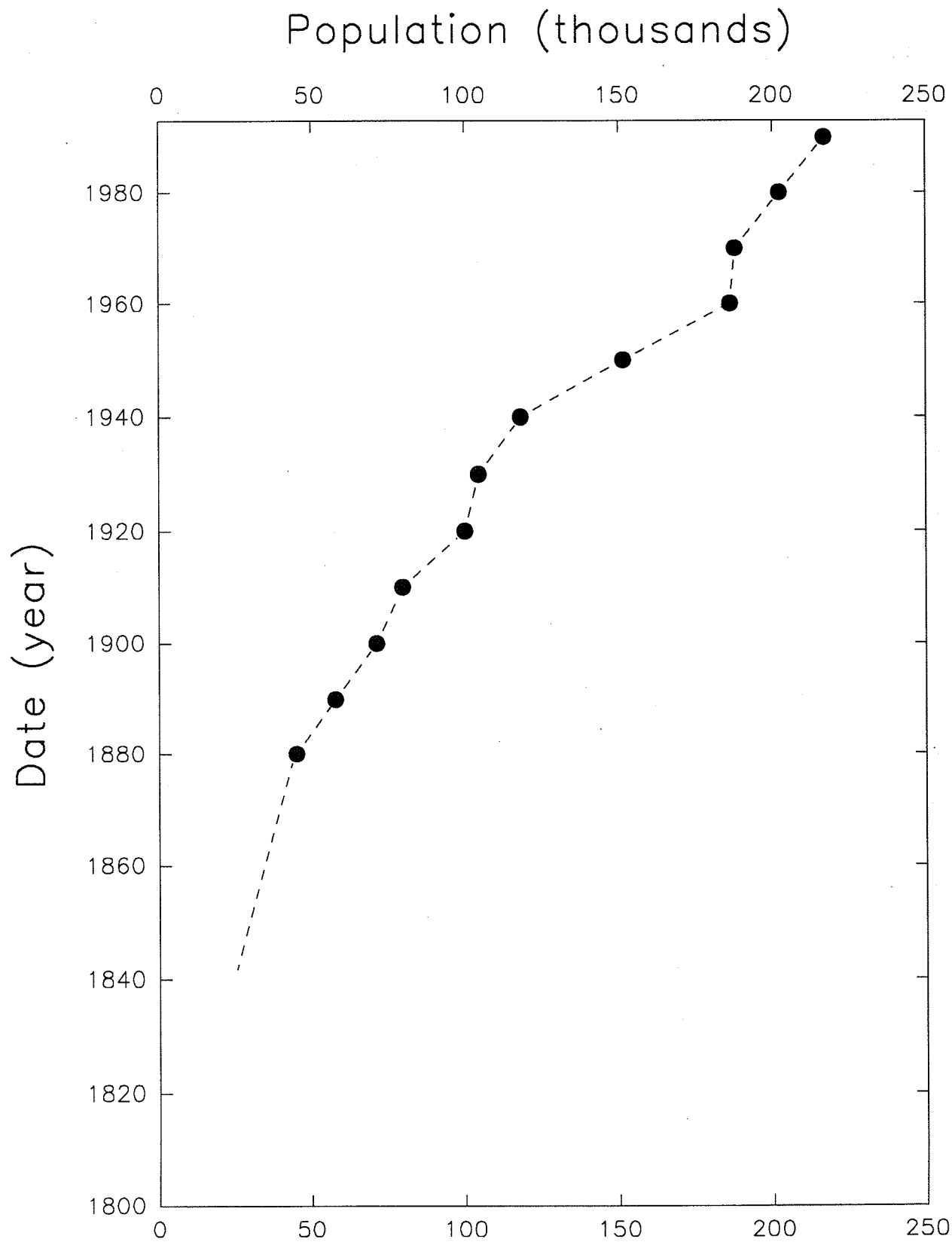
Figure 60.   Population Growth for Chatham County, Georgia
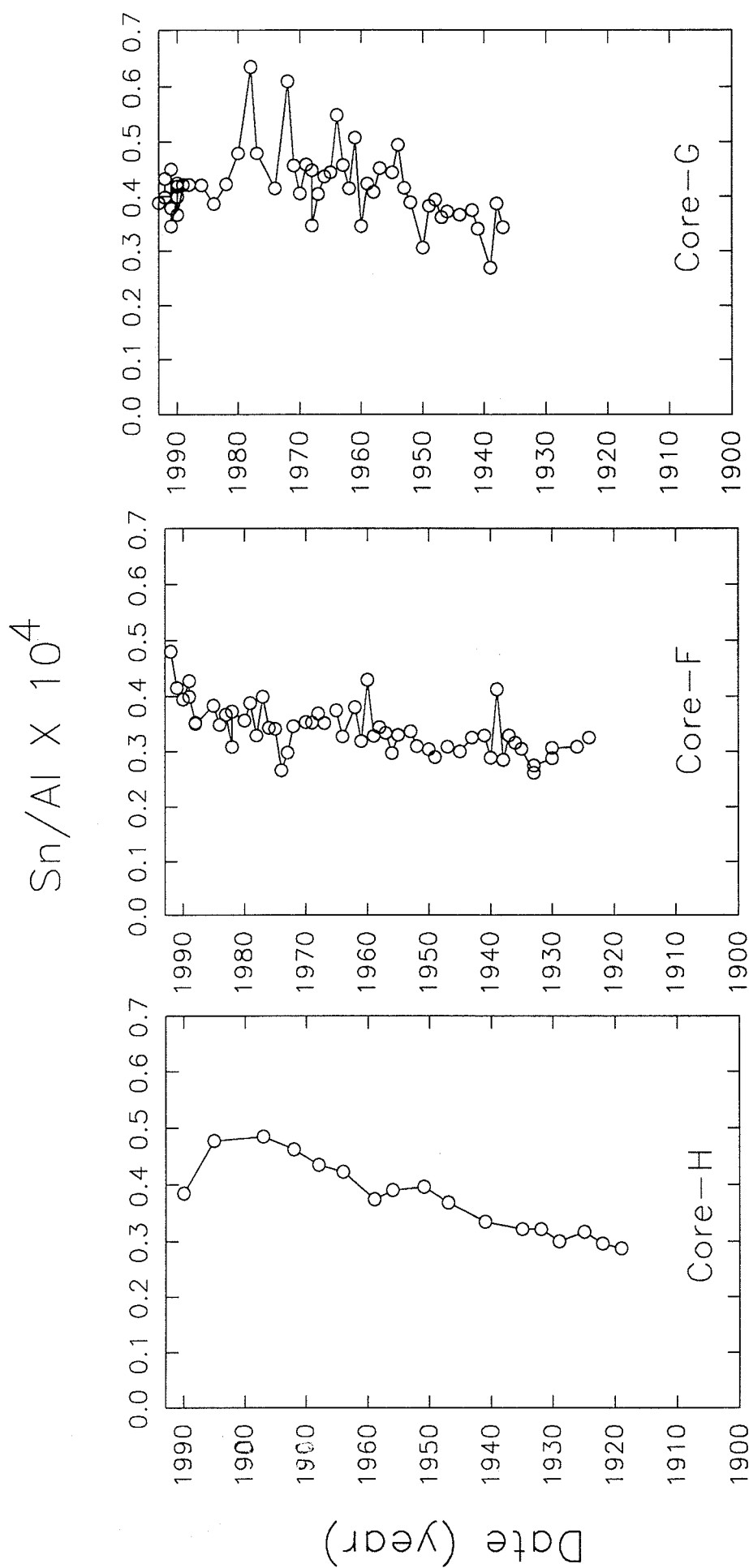
Figure 61.   Sn/Al Ratio in Sediments versus Date
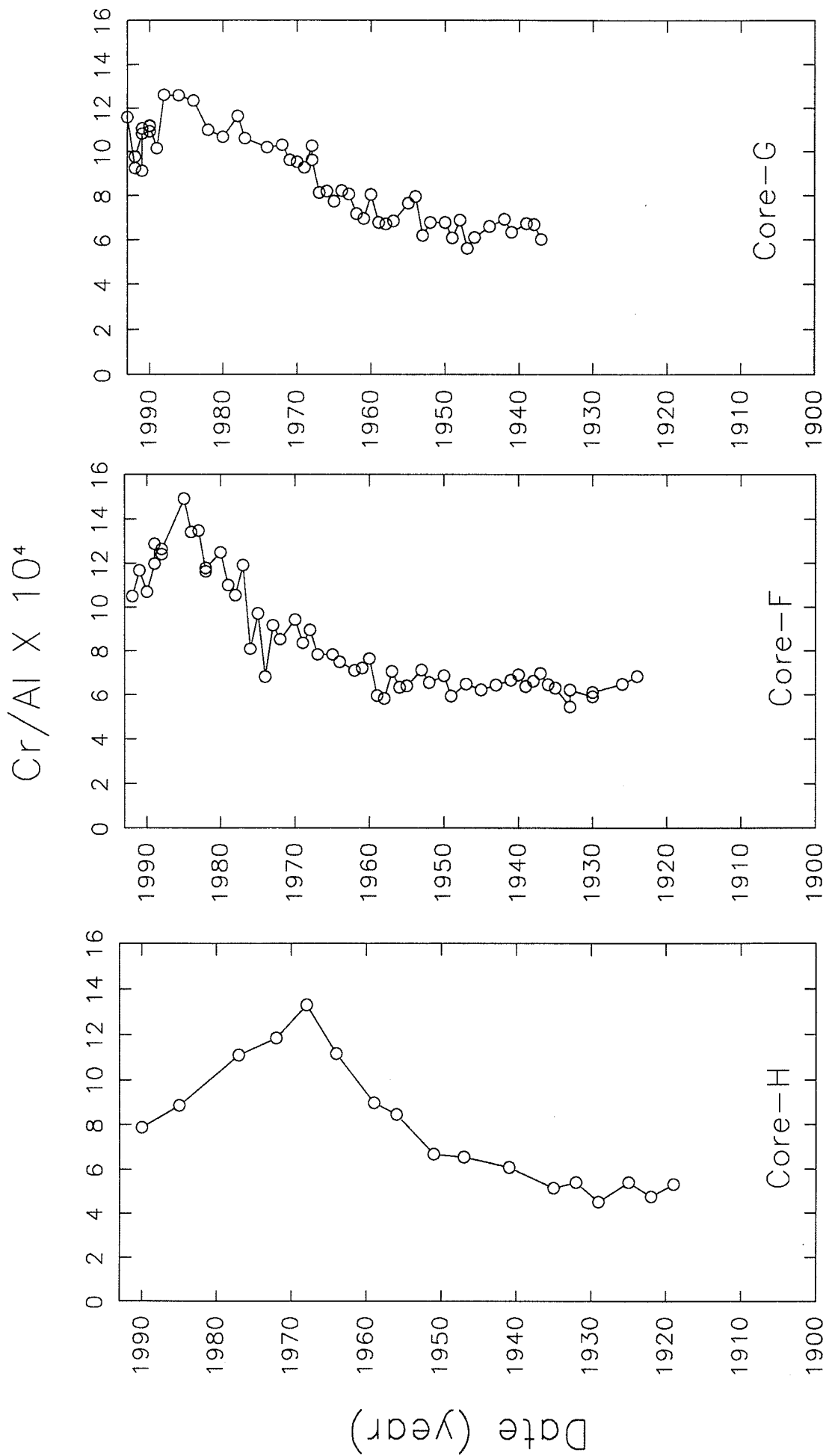
Figure 62. Cr/Al Ratio in Sediments versus Date
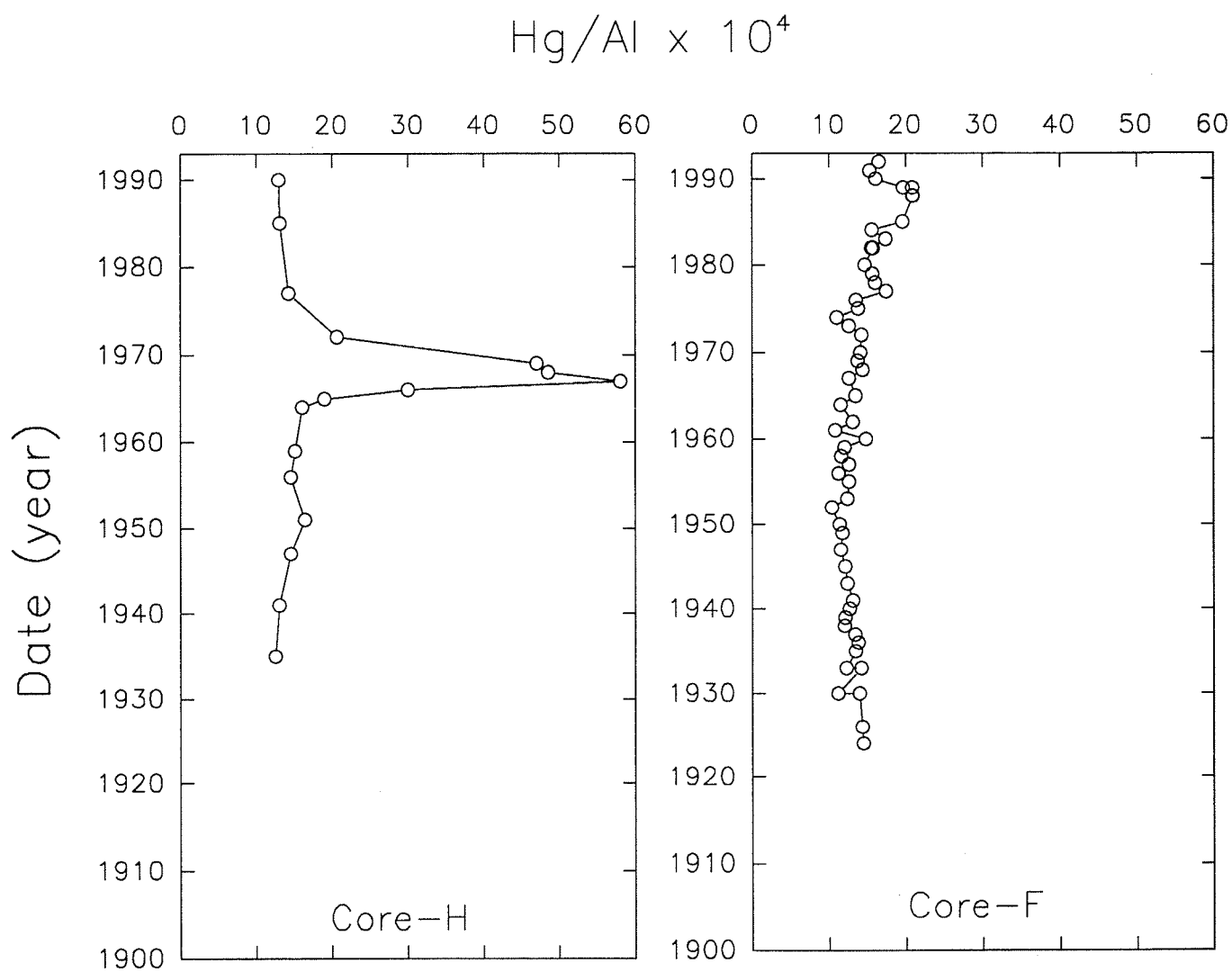
Figure 63.   Hg/Al Ratio in Sediments versus Date

Pb/Al X 10^4
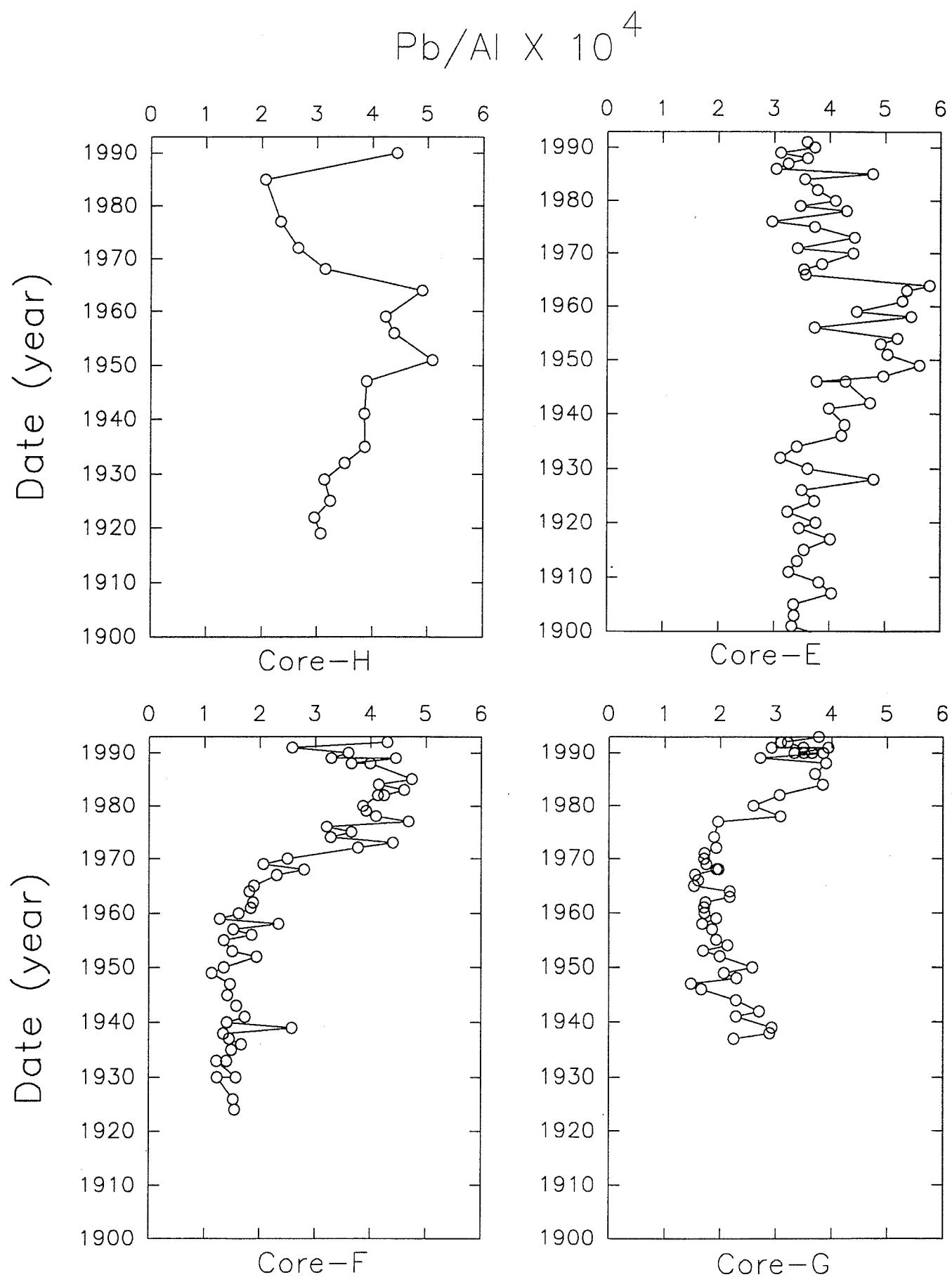
Figure 64.   Pb/Al Ratio in Sediments versus Date
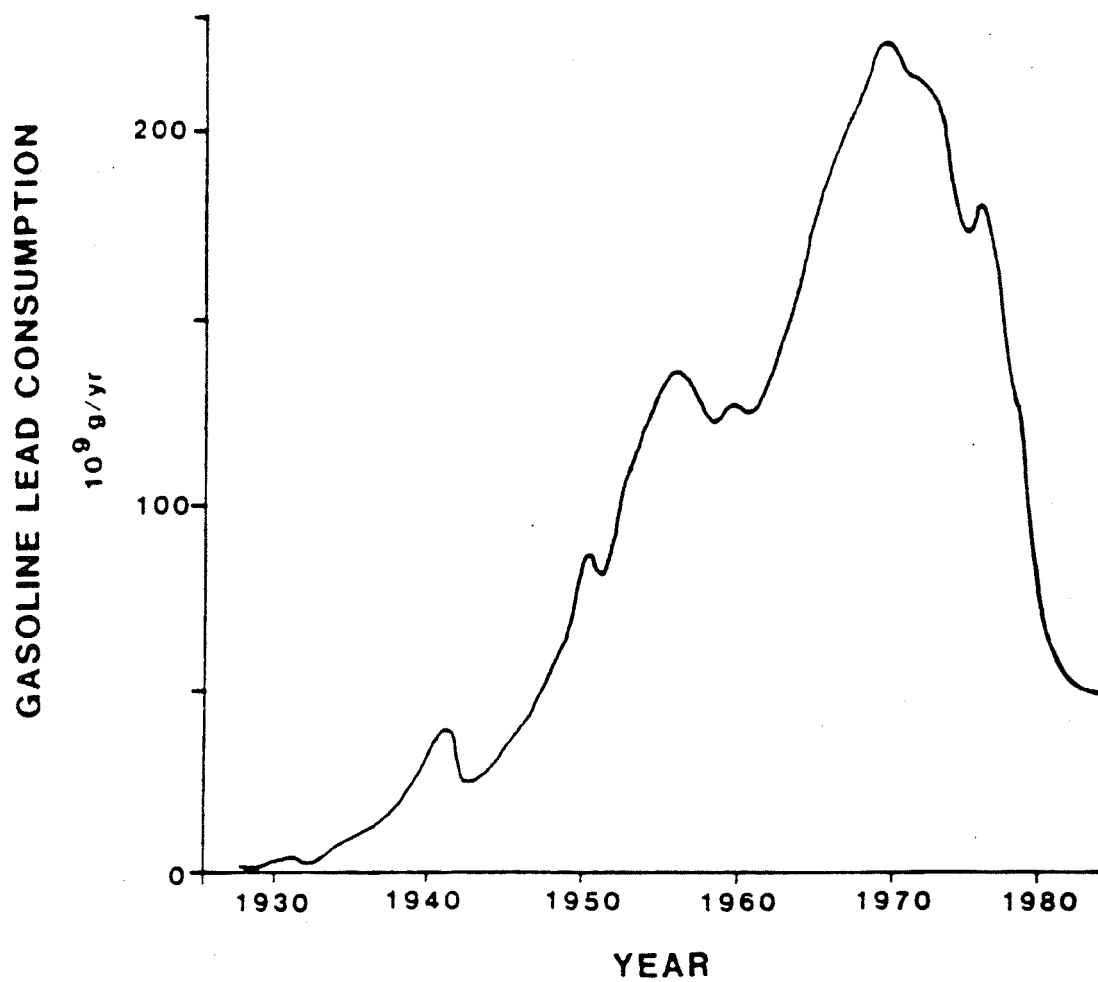
Figure 65. Lead Consumption as Alkyl Leaded Gasoline in the U.S.

Table 1.

PAH concentrations in core F (ng/gdw)

| DEPTH (cm) | 01-02 | 03-04 | 06-07 | 09-10 | 12-13 | 15-16 | 18-19 | 21-22 | 24-25 | 27-28 | 30-31 | 37-38 | 43-44 | 53-54 |
AGE	1992	1990	1987	1984	1981	1977	1975	1971	1968	1963	1960	1951	1940	1925
naphthalene	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
2-methylnaphthalene	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
1-methylnaphthalene	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Biphenyl	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
2,6 dimethylnaphthalene	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
acenaphthylene	BDL	BDL	BDL	BDL	13	11	12	BDL	BDL	BDL	BDL	BDL	BDL	BDL
acenaphthene	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
fluorene	BDL	BDL	BDL	BDL	11	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
phenanthrene	28	49	59	73	61	63	64	40	38	38	43	15	16	13
anthracene	BDL	BDL	BDL	11	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
fluoranthene	59	81	82	126	100	104	109	72	78	76	75	38	40	33
pyrene	77	163	142	211	167	171	227	144	138	162	179	44	60	53
benzo(a)anthracene	22	29	32	41	30	32	32	24	16	22	41	40	21	21
chrysene	26	35	38	48	38	42	46	32	29	26	18	38	15	19
benzo(b)fluoranthene	30	56	56	74	53	80	66	51	55	38	86	71	45	37
benzo(k)fluoranthene	20	31	28	35	27	39	36	28	29	24	27	45	26	20
benzo(e)pyrene	12	24	19	27	22	34	29	24	24	19	34	36	23	21
benzo(a)pyrene	12	24	17	18	BDL	13	10	BDL	BDL	BDL	40	43	12	27
perylene	38	49	48	59	23	27	51	30	BDL	52	26	76	42	39
indeno(1,2,3)pyrene	19	39	37	40	42	66	66	51	37	41	45	88	26	33
dibenz(a,h)anthracene	BDL	15	BDL	BDL	12	16	15	BDL	BDL	BDL	BDL	17	BDL	BDL
benzo(g,h,i)perylene	16	34	17	30	34	46	48	44	30	33	38	85	20	27
Total PAH	359	630	576	794	633	743	811	540	475	531	652	636	347	345

BDL: Below Detection Limit < 10 ng/gdw

Table 2.

PAH concentrations in core E (ng/gdw)

| DEPTH (cm) | 00-01 | 03-04 | 06-07 | 09-10 | 12-13 | 15-16 | 18-19 | 21-22 | 24-25 | 30-31 | 43-44 | 50-51 | 55-56 |
AGE	1993	1989	1985	1981	1977	1972	1966	1963	1958	1948	1923	1909	1900
naphthalene	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	19	BDL	BDL	BDL
2-methylnaphthalene	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	11	13
1-methylnaphthalene	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	11	13
Biphenyl	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
2,6 dimethylnaphthalene	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	10	14
acenaphthylene	BDL	BDL	BDL	BDL	12	19	146	42	BDL	13	BDL	18	36
acenaphthene	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	13
fluorene	206	BDL	BDL	BDL	BDL	BDL	BDL	27	BDL	11	BDL	19	32
phenanthrene	54	33	13	23	25	40	31	35	22	39	34	58	79
anthracene	40	16	BDL	BDL	12	15	15	17	BDL	20	18	18	47
fluoranthene	144	125	55	85	122	126	146	167	42	199	215	197	340
pyrene	125	126	56	88	120	186	188	184	98	170	239	285	337
benzo(a)anthracene	41	58	16	31	42	44	62	77	22	72	65	108	424
chrysene	51	66	18	42	49	53	76	100	22	106	86	133	866
benzo(b)fluoranthene	49	57	25	40	51	41	94	97	29	102	76	171	611
benzo(k)fluoranthene	32	30	BDL	25	28	32	56	69	19	50	54	114	426
benzo(e)pyrene	20	21	BDL	17	22	18	44	46	12	45	34	76	288
benzo(a)pyrene	21	23	BDL	10	27	30	59	73	15	44	47	70	464
perylene	55	140	40	64	116	100	129	472	94	469	469	294	351
indeno(1,2,3)pyrene	19	17	BDL	20	17	20	30	53	14	31	32	98	192
dibenz(a,h)anthracene	BDL	BDL	BDL	BDL	BDL	BDL	BDL	11	BDL	BDL	BDL	20	46
benzo(g,h,i)perylene	12	BDL	BDL	15	12	16	24	41	BDL	27	19	65	153
Total PAH	868	711	223	462	653	742	1100	1511	389	1417	1388	1776	4744

BDL: Below Detection Limit < 10 ng/gdw

Table 3

PAH concentrations in core H (ng/gdw)

DEPTH (cm)	00-01	11-12	21-22	32-33	43-44	90-95	110-115	130-135	150-155	175-180	195-200	220-230	345-355	465-475	515-525
AGE	1993	1989	1985	1979	1976	1967	1962	1958	1954	1948	1944	1937	1928	1922	1920
naphthalene	BDL	BDL	12	BDL	BDL	15	28	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
2-methylnaphthalene	BDL	BDL	13	BDL	BDL	24	46	33	31	BDL	BDL	BDL	BDL	BDL	16
1-methylnaphthalene	BDL	15	30	BDL	BDL	11	19	BDL	12	BDL	BDL	BDL	BDL	BDL	BDL
Biphenyl	16	21	38	BDL	24	17	26	20	21	BDL	BDL	BDL	BDL	BDL	BDL
2,6-dimethylnaphthalene	BDL	BDL	BDL	BDL	BDL	26	44	39	44	BDL	30	17	BDL	BDL	BDL
acenaphthylene	10	BDL	10	BDL	12	17	50	63	105	.	BDL	BDL	BDL	BDL	BDL
acenaphthene	BDL	BDL	BDL	BDL	BDL	23	66	92	76	11	22	10	BDL	BDL	BDL
fluorene	12	13	16	14	20	80	144	170	161	23	36	18	13	BDL	BDL
phenanthrene	52	39	57	46	55	180	354	518	251	47	23	74	48	15	38
anthracene	24	16	23	24	30	73	185	172	189	30	BDL	37	10	BDL	BDL
fluoranthene	121	101	133	151	179	393	542	1932	1113	106	130	299	138	37	75
pyrene	122	113	163	202	212	488	497	1701	985	337	267	429	117	38	77
benzo(a)anthracene	47	37	54	62	63	135	347	524	702	58	167	187	48	20	37
chrysene	52	40	56	53	51	127	271	540	423	66	59	223	59	26	45
benzo(b)fluoranthene	60	48	72	69	76	137	314	358	684	57	194	156	50	27	39
benzo(k)fluoranthene	36	31	47	43	49	84	207	213	425	30	120	119	36	19	30
benzo(e)pyrene	29	22	34	31	32	59	127	148	276	21	92	70	25	13	20
benzo(a)pyrene	36	27	35	43	41	86	170	154	379	23	121	104	40	16	31
perylene	89	134	165	252	234	236	301	339	464	140	43	241	664	812	687
indeno(1,2,3)pyrene	33	30	38	27	35	62	106	119	395	17	151	111	29	20	28
dibenz(a,h)anthracene	BDL	BDL	BDL	BDL	BDL	17	24	19	99	BDL	33	26	BDL	BDL	BDL
benzo(g,h,i)perylene	30	29	39	23	33	58	79	84	321	BDL	123	89	25	19	27
Total PAH	768	715	1035	1038	1145	2348	3946	7237	7159	978	1614	2209	1303	1062	1152

BDL: Below Detection Limit < 10 ng/gdw

TABLE 4.

PCB CONCENTRATIONS IN CORE H

Depth (cm)	Time (Date)	PCB Congeners ——ng/g——																				Total
		8	18	29	52	44	66	101	77	118	153	105	138	126	187	128	180	170	195	206	209	
0-1	1993	0.63	2.29	3.77	2.38	0.71	1.49	2.54	2.13	0.78	0.83	0.62	1.12	0.81	0.92	0.45	0.21	0.24	0.08	¹BDL	BDL	17.47
11-12	1988	BDL	1.05	1.25	1.89	1.07	2.28	1.71	2.94	0.89	1.15	0.71	1.37	0.43	1.02	0.46	0.31	0.30	0.13	BDL	BDL	22.21
21-22	1985	BDL	1.89	2.73	1.96	1.18	2.22	2.53	0.33	0.64	0.56	0.44	0.62	0.25	0.30	0.18	0.14	0.20	BDL	0.12	BDL	17.37
32-33	1979	BDL	0.90	1.43	0.88	0.83	1.93	1.76	2.69	1.01	0.76	0.73	0.95	0.51	1.02	0.47	0.14	0.16	0.10	BDL	BDL	16.27
43-44	1975	BDL	1.37	1.99	1.07	0.28	2.85	2.64	0.27	1.03	1.08	0.94	1.16	0.67	0.16	0.42	0.29	0.23	0.11	BDL	BDL	16.55
90-95	1967	BDL	6.03	4.30	1.47	2.87	4.92	3.54	3.93	1.27	0.99	0.67	0.95	0.19	0.33	0.26	0.23	0.19	0.04	BDL	BDL	32.20
110-115	1962	BDL	1.57	3.15	3.17	1.50	1.55	2.19	2.60	0.46	0.88	0.41	0.38	BDL	0.25	0.11	0.23	0.08	0.07	BDL	BDL	18.59
130-135	1958	BDL	BDL	2.92	3.90	1.56	1.08	1.45	1.80	0.38	0.62	BDL	0.26	BDL	0.35	BDL	0.06	BDL	BDL	BDL	BDL	14.38
150-155	1954	BDL	BDL	2.29	2.82	0.81	1.92	2.06	2.46	BDL	0.62	BDL	0.43	BDL	0.50	BDL	0.11	BDL	BDL	BDL	BDL	14.01
175-180	1948	BDL	BDL	1.27	3.18	0.74	1.13	1.06	1.11	0.12	0.21	0.15	BDL	BDL	0.13	BDL	BDL	BDL	BDL	BDL	BDL	9.09
195-200	1944	BDL	0.87	0.67	2.02	0.55	0.94	0.99	0.97	0.23	0.17	0.24	0.12	BDL	0.11	BDL	BDL	BDL	0.18	0.15	0.12	8.06
220-230	1937	BDL	BDL	0.51	BDL	0.29	0.46	0.38	0.55	0.19	0.12	0.15	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	2.64
345-355	1928	BDL	BDL	0.81	BDL	0.40	0.95	0.74	0.26	²BQL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	3.15
465-475	1922	BDL	BDL	0.25	0.28	0.04	0.72	0.50	0.40	0.14	BDL	BDL	0.08	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	2.42
515-525	1920	BDL	BDL	BQL	0.17	0.24	0.77	0.71	0.25	BQL	BDL	BDL	BQL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	2.13

¹ BDL - Below Detection Limit   ² BQL - Below Quantification Limit

TABLE 5.

PCB CONGENERS IN CORE F

Depth (cm)	Time (Date)	PCB Congeners —————————————————————————————————— ng/g ——————————————————————————————————																					Total
		8	18	29	52	44	66	101	77	118	153	105	138	126	187	128	180	170	195	206	209	
1-2	1992	0.46	[1]BDL	5.11	1.84	4.26	3.71	2.83	2.13	0.68	0.74	0.37	0.88	0.29	0.88	0.34	0.08	0.71	BDL	0.27	BDL	25.58
2-4	1989	BDL	BDL	9.31	1.93	5.43	7.84	6.37	4.74	1.33	1.00	1.05	1.05	0.25	0.49	0.24	0.28	1.54	BDL	BDL	BDL	42.85
6-7	1987	0.97	3.04	5.56	1.23	3.11	4.72	4.12	3.61	1.21	0.88	0.82	1.01	0.20	0.32	0.23	0.28	2.28	0.09	BDL	BDL	33.67
9-10	1983	0.41	7.10	22.65	10.84	4.64	5.50	5.27	0.26	0.96	1.04	0.92	1.35	0.17	0.34	0.30	0.48	1.81	0.19	BDL	BDL	64.22
12-13	1980	0.45	3.34	9.28	3.09	1.89	2.66	4.62	0.35	0.82	0.82	0.43	0.91	0.14	0.26	0.20	0.34	2.67	0.11	BDL	BDL	32.35
15-16	1977	0.56	3.86	7.54	1.55	1.14	3.95	5.98	0.56	1.09	1.17	0.48	1.29	0.35	0.82	0.42	0.40	0.93	0.16	BDL	BDL	32.26
18-19	1974	1.94	BDL	13.92	2.83	7.44	10.21	8.31	6.34	1.78	1.26	1.05	1.13	0.38	0.58	0.42	0.18	0.43	0.08	BDL	BDL	58.23
21-22	1970	1.04	BDL	10.22	2.44	5.62	7.95	6.55	4.55	1.26	0.99	0.90	1.08	0.30	0.37	0.41	0.17	0.26	BDL	BDL	BDL	44.11
24-25	1967	9.56	2.67	35.36	13.37	23.02	3.28	3.00	2.15	0.54	2.13	1.47	2.07	1.02	2.74	1.06	2.35	BDL	0.23	0.24	0.23	106.00
27-28	1962	0.54	3.79	6.84	1.51	3.89	6.00	5.06	0.70	0.87	1.06	0.99	0.15	0.36	0.32	0.18	0.20	0.14	0.14	0.10	BDL	32.75
30-31	1959	0.65	4.33	9.64	2.84	5.04	2.88	4.64	0.56	0.78	0.79	0.76	0.58	0.28	0.11	0.09	0.09	0.08	0.10	BDL	BDL	34.23
37-38	1950	0.68	0.54	1.26	1.74	0.89	1.44	0.94	1.01	0.22	0.22	0.30	0.16	0.28	0.51	0.14	0.15	BDL	0.09	BDL	BDL	10.54
43-44	1939	0.29	1.64	2.63	1.40	0.38	1.23	1.94	0.30	0.24	0.31	0.29	0.23	0.14	0.30	0.11	0.07	BDL	0.07	BDL	BDL	11.57
53-54	1925	BDL	BDL	2.52	1.39	1.42	2.01	1.63	1.20	0.30	0.17	0.19	0.15	0.07	0.09	0.03	0.04	BDL	BDL	BDL	BDL	11.16

[1] BDL - Below Detection Limit

TABLE 6.

PCB CONCENTRATIONS IN CORE E

Depth (cm)	Time (Date)	PCB Congeners -----ng/g-----																				Total
		8	18	29	52	44	66	101	77	118	153	105	138	126	187	128	180	170	195	206	209	
0-1	1993	0.48	BDL¹	308	1.42	1.76	2.89	2.90	2.47	0.91	0.74	0.72	0.78	0.37	0.26	0.30	0.18	0.18	0.09	BDL	BDL	19.55
3-4	1988	BDL	BDL	2.22	2.08	1.24	2.20	1.76	1.40	0.53	0.45	0.30	0.37	0.27	0.29	0.13	0.12	0.12	BDL	BDL	BDL	13.49
27-28	1953	BDL	BDL	BDL	2.47	5.37	7.17	5.55	3.85	0.87	0.55	0.51	0.36	0.19	0.21	0.08	0.07	BDL	0.08	BDL	BDL	27.31
43-44	1922	BDL	BDL	1.02	1.26	0.69	1.18	1.06	1.14	0.30	0.30	0.26	0.22	0.13	0.27	BDL	BDL	BDL	BDL	BDL	BDL	6.82
55-56	1899	0.67	BDL	3.48	1.92	2.08	2.73	2.07	1.72	0.30	0.26	0.26	0.18	0.19	0.28	BDL	BDL	BDL	BDL	BDL	BDL	12.00

¹ BDL - Below Detection Limit

TABLE 7.

LIMITS OF DETECTION (LOD), LIMITS OF QUANTIFICATION (LOQ), AND METHOD DETECTION LIMIT (MDL) FOR
POLYCHLORINATED BIPHENYLS (PCBs)

PCB Congener #	LOD (pg)	LOQ (pg)	MDL (pg/G)
PCB-08	0.70	2.34	78.00
PCB-18	0.42	1.42	47.33
PCB-29	0.25	0.85	28.33
PCB-52	0.55	1.83	61.00
PCB-44	0.18	0.62	20.67
PCB-66	0.28	0.93	31.00
PCB-101	0.59	1.96	65.33
PCB-77	0.22	0.75	25.00
PCB-118	0.24	0.82	27.33
PCB-153	0.24	0.80	26.67
PCB-105	0.08	0.28	9.33
PCB-138	0.11	0.36	12.00
PCB-126	0.21	0.71	23.67
PCB-187	0.26	0.87	29.00
PCB-128	0.14	0.47	15.67
PCB-180	0.15	0.51	17.00
PCB-170	0.23	0.76	25.33
PCB-195	0.27	0.90	30.00
PCB-206	0.46	1.52	50.67
PCB-209	0.52	1.73	57.67

LOD = Limit of Detection: Three times standard deviation of baseline noise
LOQ = Limit of Quantification: Ten times standard deviation of baseline noise
MDL = Method Detection Limit: LOQ sample extract volume/sample weight
MDL was generalized for 15 gms of dry sediment

TABLE 8.

PESTICIDES IN CORE F

Depth (cm)	Time (Date)	Lindane	Heptachlor	H. Epoxide	Dieldrin	Aldrin	Mitex	Trans-Nonachlor	Alpha-Chlordane	Endrin	HCB[a]	2,4'-DDT	4,4'-DDT	2,4'-DDE	4,4'-DDE	2,4'-DDD	4,4'-DDD
		------							---ng/g---								
1-2	1992	1.55	BDL[b]	BDL	1.80	0.51	BDL	0.86	0.22	BDL	BDL	BDL	BDL	0.26	2.01	BDL	0.98
2-4	1989	0.58	BDL	BDL	1.09	0.69	BDL	BDL	0.22	BDL	BDL	BDL	BDL	BDL	2.81	0.42	0.85
6-7	1987	1.28	BDL	BDL	2.70	BDL	BDL	BDL	0.23	BDL	BDL	BDL	BDL	BDL	4.68	0.95	2.35
9-10	1984	0.97	BDL	BDL	3.63	BDL	BDL	BDL	0.16	BDL	BDL	BDL	BDL	BDL	9.98	1.29	3.61
12-13	1980	0.87	BDL	BDL	2.08	BDL	BDL	BDL	0.19	BDL	BDL	BDL	BDL	BDL	6.20	0.98	2.69
15-16	1977	0.69	BDL	BDL	1.54	BDL	BDL	BDL	0.33	BDL	BDL	BDL	BDL	BDL	6.45	1.06	2.35
18-19	1974	0.74	BDL	BDL	1.30	BDL	BDL	BDL	0.27	BDL	BDL	BDL	BDL	0.16	5.18	1.05	2.47
21-22	1970	0.52	BDL	BDL	0.47	BDL	BDL	BDL	0.22	BDL	BDL	BDL	BDL	0.12	1.44	0.45	0.87
24-25	1967	0.56	BDL	BDL	0.40	BDL	BDL	BDL	0.27	BDL	BDL	BDL	BDL	BDL	BDL	0.33	0.58
27-28	1962	0.55	BDL	BDL	0.38	BDL	BDL	BDL	0.17	BDL	BDL	BDL	BDL	BDL	1.25	0.36	0.29
30-31	1959	0.57	BDL	BDL	0.41	1.19	BDL	BDL	0.22	BDL	BDL	BDL	BDL	BDL	1.15	0.23	0.32
37-38	1950	0.17	BDL	BDL	0.19	0.15	BDL	BDL	0.07	BDL	BDL	BDL	0.68	BDL	1.00	0.20	0.16
43-44	1939	0.40	BDL	BDL	0.22	0.26	BDL	BDL	0.14	BDL	BDL	BDL	BDL	BDL	0.25	0.16	0.11
53-54	1925	0.24	BDL	BDL	0.20	0.27	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.12	0.09

[a] Hexachlorobenzene
[b] BDL - Below Detection Limit

TABLE 9.

PESTICIDES IN CORE H

Depth (cm)	Time (Date)	Lindane	Heptaclor	H. Epoxide	Dieldrin	Aldrin	Mirex	Trans-Nonachlor	Alpha-Chlordane	Endrin	HCB	2,4'-DDT	4,4'-DDT	2,4'-DDE	4,4'-DDE	2,4'-DDD	4,4'-DDD
							ng/g										
0 - 1	1933	0.66	BDL[1]	BDL	1.00	0.48	BDL	BDL	0.18	BDL	BDL	BDL	BDL	BDL	1.69	0.35	0.79
11 - 12	1988	0.22	BDL	BDL	0.31	BDL	BDL	BDL	0.13	BDL	BDL	BDL	BDL	BDL	2.49	0.38	0.49
21 - 22	1985	0.24	1.04	BDL	0.32	0.33	BDL	BDL	0.25	BDL	BDL	BDL	BDL	BDL	3.21	0.40	0.50
32 - 33	1979	0.28	BDL	BDL	0.25	0.18	BDL	BDL	0.30	BDL	BDL	BDL	BDL	BDL	2.77	0.24	0.59
43 - 44	1975	0.30	BDL	BDL	0.53	0.19	BDL	BDL	0.40	BDL	BDL	BDL	BDL	BDL	3.74	0.34	0.79
90 - 95	1967	0.38	BDL	0.07	1.99	0.33	BDL	BDL	0.16	0.08	BDL	BDL	BDL	BDL	11.76	1.57	6.23
110 - 115	1962	0.34	BDL	0.10	0.13	0.45	BDL	BDL	0.32	0.23	BDL	BDL	BDL	BDL	5.43	0.53	2.95
130 - 135	1958	0.26	BDL	0.09	BDL	0.50	BDL	BDL	0.32	BDL	BDL	BDL	BDL	BDL	3.71	0.36	2.62
150 - 155	1954	0.24	BDL	BDL	0.13	BDL	BDL	BDL	0.15	BDL	BDL	BDL	BDL	BDL	2.43	0.29	2.67
175 - 180	1948	0.29	BDL	BDL	0.36	BDL	BDL	BDL	0.18	BDL	BDL	BDL	BDL	BDL	0.12	0.14	0.14
195 - 200	1944	0.24	BDL	BDL	0.12	BDL	BDL	BDL	0.08	BDL	BDL	BDL	BDL	BDL	0.14	0.14	BDL
220 - 230	1937	0.20	BDL	BDL	0.26	BDL	BDL	BDL	0.13	BDL	BDL	BDL	BDL	BDL	0.12	0.17	BDL
345 - 355	1928	0.31	BDL	BDL	0.43	0.16	BDL	0.20	0.15	BDL	BDL	BDL	BDL	BDL	0.74	0.22	0.19
465 - 475	1922	BDL	BDL	BDL	0.16	BDL	BDL	BDL	0.26	BDL	BDL	BDL	BDL	BDL	0.22	BDL	0.19
515 - 525	1920	0.27	BDL	BDL	0.15	BDL	BDL	0.14	0.11	BDL	BDL	BDL	BDL	BDL	0.33	BDL	BDL

[1]BDL - Below Detection Limit

TABLE 10.

LIMITS OF DETECTION (LOD), LIMITS OF QUANTIFICATION (LOQ), AND METHOD DETECTION LIMIT (MDL) FOR SELECTED PESTICIDES

PESTICIDES	LOD	LOQ	MDL (pg/G)
Lindane	0.62	2.08	69.19
Hepoxide	0.18	0.61	20.37
2,4'-DDE	0.76	2.53	84.40
Alpha-chlordane	0.54	1.79	59.51
Trans-nonachlor	0.50	1.67	55.66
4,4'-DDE	0.56	1.86	62.05
Dieldrin	0.54	1.79	59.51
2,4'-DDD	0.74	2.45	81.67
4,4'-DDD	0.49	1.62	54.02
2,4'-DDT	1.13	3.75	125.04
4,4'-DDT	1.87	6.24	208.12
Mirex	2.15	7.17	238.98
Endrin	5.76	19.20	640.14
Aldrin	8.86	29.53	984.29
Hexachlorobenzene	6.14	20.48	682.69
Heptachlor	6.50	21.67	722.33

LOD = Limit of Detection: Three times standard deviation of baseline noise

LOQ = Limit of Quantification: Ten times standard deviation of baseline noiseMDL = Method Detection Limit: LOQ sample extract volume/sample weight

MDL was generalized for 15 gms of dry sediment

TABLE 11.

Tributyltin (TBT), Dibutyltin (DBT), and Monobutyltin (MBT) Concentrations in Core E

Depth (cm)	Time (date)	TBT	DBT	MBT
		|---------ng/g---------|	
0 - 1	1993	8.2	4.2	BDL[1]
3 - 4	1988	BDL	BDL	BDL
27 - 28	1953	BDL	BDL	BDL

[1]BDL - Below Detection Limit, < 4 ng/g

TABLE 12.

Tributyltin (TBT), Dibutyltin (DBT), and Monobutyltin (MBT) Concentrations in Core F

Depth (cm)	Time (date)	TBT	DBT	MBT
		|-------ng/g-------|	
1 - 2	1992	BDL[1]	BDL	BDL
2 - 4	1989	BDL	BDL	BDL
6 - 7	1987	BDL	BDL	BDL

[1]BDL – Below Detection Limit, < 4 ng/g

TABLE 13.

Tributyltin (TBT), Dibutyltin (DBT), and Monobutyltin (MBT) Concentrations in Core II

Depth (cm)	Time (date)	TBT	DBT	MBT
			---------ng/g---------	
0 - 1	1993	7.5	4.5	BDL[1]
11 - 12	1988	BDL	BDL	BDL
21 - 22	1985	BDL	BDL	BDL
32 - 33	1979	BDL	BDL	BDL

[1]BDL - Below Detection Limit, < 4 ng/g

APPENDIX I.

Quality Assurance Project Plan for the Study of Historical Record of Sediment
Contamination in the Savannah Estuary

Table of Contents

1.0 Project Description

This project is to analyze sediment core samples for trace element and organic contaminant content. These data will be used to determine changes in the sediment concentrations of various trace elements and organics in dated cores. This will allow us to obtain a historical record of contamination in the Savannah Estuary.

The trace elements and organic contaminants that will be analysed are listed in the QA Objectives Table (Section 3.0).

2.0 Project Organization and Responsibility

Project organization and line of authority is shown in Figure 1. Responsibilities are as follows:

Project Manager: Is responsible for management of project, insuring that all required analyses have been performed and preparation of reports. Along with the Laboratory Director, provides a point of contact.

Laboratory Directors: Are responsible for scheduling analyses and procedures. Will track sample progress and report results to the project manager.

QA Officer: Keeps quality assurance records and ascertains whether analyses meet requisite quality assurance parameters. Prepares quality assurance reports.

Analyst: Performs analyses and procedures under the direction of the Laboratory Director.

Figure 1
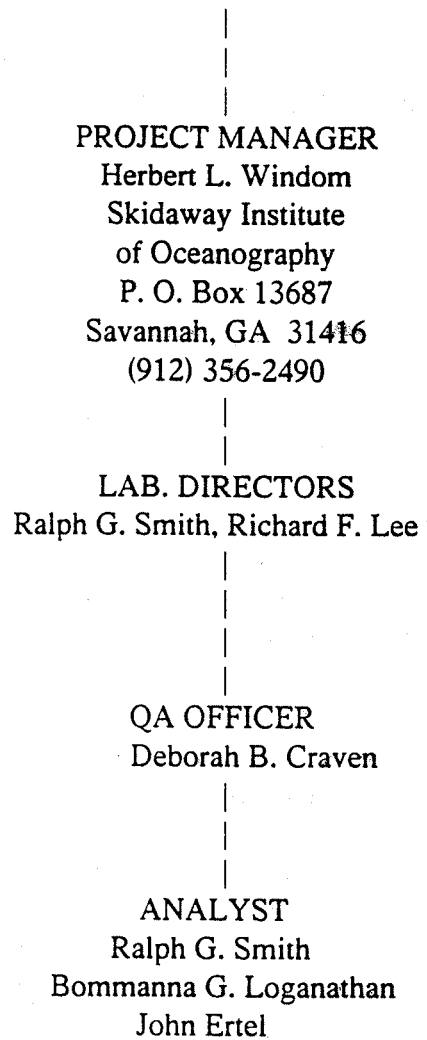
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3.0 QA Objectives Table

Measurement Parameter	Reference Section	Method	Precision (%RSD)	Accuracy (%R)	Detection Limits (ppm)
Aluminum	7.2	ICP/MS	10	90	10
Arsenic	7.2	ICP/MS	10	85	0.08
Barium	7.2	ICP/MS	10	90	0.02
Cadmium	7.2	ICP/MS	10	85	0.02
Chromium	7.2	ICP/MS	10	85	0.99
Copper	7.2	ICP/MS	10	90	0.13
Iron	7.2	ICP/MS	10	90	10
Lead	7.2	ICP/MS	10	80	0.04
Lithium	7.2	ICP/MS	10	85	0.58
Manganese	7.2	ICP/MS	10	90	1.0
Mercury	7.2,7.3	ICP/MS	10	85	0.007
Nickel	7.2	ICP/MS	10	85	0.25
Silver	7.2	ICP/MS	10	90	0.001
Titanium	7.2	ICP/MS	10	85	5.0
Vanadium	7.2	ICP/MS	10	90	0.005
Zinc	7.2	ICP/MS	10	85	0.38
Total organic C	7.4	CHN	10	90	10
Total Kjeldahl N	7.4	CHN	10	90	10
Total phosphorus	7.2	ICP/MS	10	90	5.1
Total carbonate	7.5	Carver	10	85	10
Naphthalene	7.6	GC/MS	10	90	0.07
Acenaphthylene	7.6	GC/MS	10	90	0.08
Acenaphthene	7.6	GC/MS	10	90	0.08
Fluorene	7.6	GC/MS	10	90	0.09
Dibenz[a,h]anthracene	7.6	GC/MS	10	90	0.23
Indeno[1,2,3-cd]pyrene	7.6	GC/MS	10	90	0.23
Phenanthrene	7.6	GC/MS	10	90	0.09
Anthracene	7.6	GC/MS	10	90	0.09
Fluoranthene	7.6	GC/MS	10	90	0.11
Pyrene	7.6	GC/MS	10	90	0.12
Chrysene	7.6	GC/MS	10	90	0.13

Benz[a]anthracene	7.6	GC/MS	10	90	0.13
Benzo[b]fluoranthrene	7.6	GC/MS	10	90	0.17
Benzo[k]fluoranthrene	7.6	GC/MS	10	90	0.17
Benzo[ghi]perylene	7.6	GC/MS	10	90	0.23

3.0 QA Objectives Table

Measurement Parameter	Reference Section	Method	Precision (%RSD)	Accuracy (%R)	Detection Limits (ppm)
Benzo[e]pyrene	7.6	GC/MS	10	90	0.17
Benzo[a]pyrene	7.6	GC/MS	10	90	0.17
Perylene	7.6	GC/MS	10	90	0.17
Aldrin	7.7	GC	10	90	0.001
Alpha-Chlordane	7.7	GC	10	90	0.0005
2,4'DDD	7.7	GC	10	90	0.001
4,4'DDD	7.7	GC	10	90	0.001
2,4'DDE	7.7	GC	10	90	0.001
4,4'DDE	7.7	GC	10	90	0.001
2,4'DDT	7.7	GC	10	90	0.0001
4,4'DDT	7.7	GC	10	90	0.0001
Dieldrin	7.7	GC	10	90	0.0001
Heptachlor epoxide	7.7	GC	10	90	0.0001
Hexachlorobenzene	7.7	GC	10	90	0.0001
Lindane	7.7	GC	10	90	0.001
Mirex	7.7	GC	10	90	0.0005
Trans-Nonachlor	7.7	GC	10	90	0.001
Endrin	7.7	GC	10	90	0.001
Polychlorinated Biphenyls					
2,4'-CL2.2,2, 5'CL3	7.7	GC	10	90	0.0005
2,4,4'-CL3	7.7	GC	10	90	0.0005
2,2', 3,5'-CL4	7.7	GC	10	90	0.0001
2,2', 5,5'-CL4	7.7	GC	10	90	0.0001
2,3', 4,4'-CL4	7.7	GC	10	90	0.0005
3,3', 4,4'-CL4	7.7	GC	10	90	0.0001
2,2', 4,5,5'-CL5	7.7	GC	10	90	0.0001
2,3,3', 4,4'-CL5	7.7	GC	10	90	0.0001
2,3', 4,4'.5-CL5	7.7	GC	10	90	0.0001
3,3'4, 4'.5-CL5	7.7	GC	10	90	0.0001

2,2'3,3'4,4'-CL6	7.7	GC	10	90	0.0001
2,2'3,4,4',5-CL6	7.7	GC	10	90	0.0001
2,2'4,4'5,5'-CL6	7.7	GC	10	90	0.0001
2,2'3,3'4,4'5-CL7	7.7	GC	10	90	0.0001
2,2'3,4',5,5'6-CL7	7.7	GC	10	90	0.0001
2,2'3,3'4,4'5,6-CL8	7.7	GC	10	90	0.0001
2,2',3,3'4,4'5,5',6-CL9	7.7	GC	10	90	0.0003
Decachlorobiphenyl-CL10	7.7	GC	10	90	0.0003
Tributyltin	7.8	GC	10	90	0.005
Dibutylin	7.8	GC	10	90	0.005
Monobutylin	7.8	GC	10	90	0.005

4.0 Sampling Procedures

Sampling shall be the responsibility of sedimentologist (sep. field sampling).

Samples from cores are transferred to glass jars (I-Chem #220 - 0250) which have been precleaned by the manufacturer to meet EPA specifications for organic and inorganics. Samples are labeled with station number and date, and immediately placed on ice. The time of collection, sample number, replicate number and location are recorded on a chain of custody sheet.

5.0 Calibration procedures and frequency

5.1 ICP/MS

The instrument is calibrated daily against aqueous standards (commercially available from several suppliers). In addition, daily checks of instrument calibration using a continuing calibration standard (e.g., NIST SRM 1643c) are made. All of these protocols are outlined in Tables 1, 2, and 3.

Standards prepared for ICP/MS are properly identified and dated. Stock standards and working standards are replaced before they reach their expiration date.

5.2 GC and GC/MS

The mass spectrometer-gas chromatograph used for PAH analysis is a Finnigan Incos 50 GC coupled with a Hewlett Packard 5890 gas liquid chromatograph. The mass spectrometer is tuned and calibrated with a FC-43 perfluorokerosene standard prior to each set of analytical runs. The standards are d8-naphthalene, d10-acenaphthalene, d10-phenanthrene, d12-chrysene, d12-perylene. Three to five point calibration curves are prepared before each batch of samples is

run using both full scale (m/z 50-400) and SIM scanning. Calibration curves are calculated from mass spectral peak area data and saved on computer disks. Concentrations in samples are calculated relative to calibration curves for appropriate instrumental conditions. The PAHS to be analyzed and the cores to be used for quantification are given in Table 5.

The pesticides and polychlorinated biphenyls are analyzed by high-resolution fused silica capillary gas chromatography with electron capture detection (Varian 3400 CX and 8220 autosampler). The instrument is calibrated with 4,4-dibromooctafluorobiphenyl. A calibration curve for each pesticide and PCB congener is prepared using standard mixtures. The pesticides to be analyzed include Aldrin, Alpha-Chlordane, 2,4'- DDD, 4,4'DDD, 2,4,'DDE, 4,4'DDE, 2,4'-DDT, 4,4'DDT, Dieldrin, Heptachlor, Heptachlor epoxide, Hexachlorobenzene, Lindane, Mirex, Trans-Nonachlor, Endrin. Polychlorinated biphenyls to be analyzed include 2,4'-CL2, 2,2,5'CL3; 2,4,4'-CL3; 2,2', 3,5'- CL4; 2,2', 5,5'-CL4; 2,3',4,4'-CL4; 3,3'4,4'-CL4; 2,2', 4,5,5'- CL5; 2,3,3',4,4'-CL5;2,3',4,4',5-CL5' 3,3'4,4'5-CL5; 2,2'3.3'4.4'-CL6; 2.2'3.4.4'5'- CL6; 2,2'4,4'5,5'-CL6; 2,2'3,3'4,4'5-CL7;2,2'3,4,4'5,5'-CL7; 2,2'3,4',5,5',6-CL7; 2,2'3,3',4,4',5,6-CL8; 2,2'3,3'4,4'5,5'6-CL9; Decachlorobiphenyl- CL10.

5.3 CHN Analyzer

The CHN Analyzer is calibrated daily according to the protocols outlined in Tables 1, 2 and 3.

5.4 Standard Preparation Protocol

Stock solutions are made in accordance with Table 1B. Volumetric flasks are used for making the stock solutions and are marked with labeling tape as to contents (i.e., Stock solution A), date and analyst. Information on standard preparations is kept in laboratory notebooks.

a)   Inorganics. The standards used for ICP/MS analyses are purchased from either Fisher, VWR or AESAR as NIST traceable standards at a concentration of 1000 ppm. Upon receipt the standards are scanned by ICP/MS for impurities and the date is marked on the sample bottle. If impurities are present in more than trace amounts the standard is rejected. The standards are kept for one year from the date of receipt.

A detailed standard preparation protocol is shown in Table 1B where A_1 is the volume (μl) of 1000 ppm standard which is diluted to 100 ml in a volumetric flask. The resulting mixture has the analyte concentrations shown for solution A. Similarly, B_1 is the volume (ml) of 1000 ppm standards used to make solution B. Solution A is standard stock trace metal solution which is subsequently diluted according to the following:

STD-A   1.0 ml aliquot is diluted in a 100 ml volumetric flask.
STD-B   0.5 ml aliquot is diluted in a 100 ml volumetric flask.
STD C   0.2 ml aliquot is diluted in a 100 ml volumetric flask.

STD-D   0.1 ml aliquot is diluted in a 100 ml volumetric flask.

All dilutions are made using Eppendorf pipettes which are periodically calibrated. The concentrations of these standards are given in Appendix E and the final solutions are made in 1% HNO3 with Baker Instra-analyzed HNO_3.

Major element standard concentrations are given in solution B of Table 1B. Additional standards may be prepared from serial dilutions of solution B or by making smaller aliquots than is shown in B1.

b)   Organics. The standards used for GC analysis are purchased from Accustandard and/or Ultra Scientific at a concentration of 10 ppm. These reference standards are certified by the American Association for Laboratory Accredation and have met all QA/QC requirements for reference materials stated in EPA's analytical methods. Upon receipt the date is marked on the sample bottle. The standards are kept for one year from the date of receipt. There are no expiration dates on the standards. The preparation protocol for these standard mixes is as follows: 10 um of 10 ppm standard mix is diluted using hexane (Fisher-Optima grade) to a volume of 10 ml in a volumetric flask. The concentration of compounds in the diluted standards are 10 ppb. Various dilutions of these standards are made to allow preparation of a standard curve for each compound. All dilutions are made using Hamilton glass syringes.

6.0 Analytical procedures

6.1 Sample digestion

Total digestion of sediment samples is done in trace metal clean Teflon beakers with high quality nitric, perchloric and hydrofluoric acids as recommended in the *FDEP Deepwater Ports Maintenance Dredging and Disposal Manual* (1984). Samples are first digested with nitric and hydrofluoric acids to break down silicate phases. The samples are then digested with perchloric acid to destroy any organic matter in the sample and taken to dryness. The residue is dissolved in dilute nitric acid, and stored in acid cleaned polyethylene vials.

_ The above digestions are carried out under clean conditions to prevent contamination during sample handling and analysis. All material that comes into contact with the sample is be rigorously cleaned. Cleaning is performed in acid baths dedicated to different types of material. This prevents cross contamination of the samples and sample containers. These baths as well as areas for drying cleaned containers are located in the Class 100 clean room. Use of clean facilities is mandatory to prevent contamination of the sample containers (and thus the sample)

by trace metal rich airborne particles.

6.2 Inductively coupled plasma-mass spectrometry (ICP-MS)

After digestion by the procedure in 7.1, samples are analyzed for Li, Al, Fe, Mn, Cd, Cu, Cr, Ni, Pb, Zn, As, Ag, V, Ba, Ti and total P by ICP/MS. An internal standard is added to every sample and standard prior to analysis. Indium is the internal standard used at a concentration of 100 ppb. The internal standard is used to compensate for detector instability which is inherent in ICP/MS. Isobaric interference corrections will be made for arsenic and vanadium. Isotope dilution methods will be used for Hg.

ICP/MS is validated for the elements listed above by EPA 6020 protocol and/or by comparison of historical values with the certified concentrations in Table 4.

6.3 Mercury analysis

All samples are spiked with an enriched ^{201}Hg isotope prior to digestion. The samples are digested with 1:1 HNO_3/HCl for one hour in a steam bath while sealed in teflon bombs. The resulting solution is analyzed by cold vapor/ICP-MS (isotope dilution method). The validation for this method is given in Table 4. A copy of the method is in Appendix H.

6.4 CHN analyzer

Total organic carbon is analyzed on a carbonate-free basis (using residue from the total carbonate analysis, see Section 8.7) using a Perkin Elmer Model 240C elemental analyzer. Since total nitrogen as measured by elemental analyzer has been shown to be comparable to total Kjeldahl nitrogen (McGeehan, S. L. and Naylor, D. V. (1988) Commun. Soil Sci. Plant Analy., 19, 493-505; Riley, K. W., Moss, T. D., Orban, H. and Quezada, R. A. (1987) Fuel, 66, 323-325) total nitrogen will be analyzed concurrently.

6.5 Total carbonate

Total carbonate is analyzed by difference between unacidified and acidified samples. Weighed aliquots of oven-dried sample will be treated with HCl until $CO2$ is no longer evolved. Acid solution will be removed by centrifugation, washed to remove chloride and recentrifuged. The carbonate-free weight will be determined after oven drying the sample. This method is a modification of that described by R.E. Carver, Editor, in Procedures in Sedimentary Petrology, 1971, Wiley, Interscience, 653 p.

6.6 Polycyclic aromatic hydrocarbons

The procedures are described in NOAA Technical Memorandum NMFS F/NWS-92F

(MacLeod *et al.*, 1985). GC-MS is validated by comparison of historical values with certified PAH concentrations in Table 7.

Prior to use, the glassware is carefully washed, rinsed, and combusted at 400°C. Solvents will be glass-distilled purity and will be checked routinely for purity. Each set of samples (about 5) will be accompanied by system and spiked blanks carried through the entire analytical procedure. Internal standards (d8-naphthalene, d10-acenaphthene, d10-phenanthrene, d12-chrysene, and d12- perylene) will be added to each sample and blank before workup to follow analytical recoveries and reproducibilities.

Approximately 30 g of freeze dried sediment is Soxlet extracted exhaustively and sequentially with CH_2Cl_2. The organic phase is concentrated to several ml and stored refrigerated until fractionation by column chromatography. The extracts are fractionated on columns of silica gel over alumina packed over activated copper to remove elemental sulfur. Aliphatic hydrocarbons are eluted with hexane (fraction SA1), while aromatic hydrocarbons:PCB:pesticides are eluted with 1:1 pentane: CH_2Cl_2 (fraction SA2). Further separation of the aromatic hydrocarbon:PCB:pesticide fraction is accomplished by Sephadex LH-20 chromatography. Standards are used to calibrate all columns before application of samples.

PAH is quantified by capillary gas chromatography-mass spectrometry utilizing full scan and selected ion monitoring (SIM) modes. An apolar DB-5 column mounted in an Hewlett Packard 5890 gas chromatograph and interfaced to a Finnigan Incos 50 mass spectrometer/data system will be used. The GC/MS is calibrated over the appropriate concentration range through construction of calibration curves and concentrations and recoveries will be based on the deuterated internal standards.

6.7 Chlorinated hydrocarbons

The procedures are described in NOAA Technical Memorandum NMFS F/NWS-92F (MacLeod *et al.*, 1985).

The internal standard is 4,4-dibromooctafluorobiphenyl which will be added to each sample and blank at a concentration similar to concentrations expected for the compounds of interest. This allows determination of recovery and reproducibility. Sediment is extracted as described above for PAH's. The concentrated extract in hexane is loaded onto a precalibrated chromatography column packed with silica gel, alumina and granular copper. The first fraction (SA1) is eluted with hexane and a second fraction (SA2) is eluted with dichloromethane in hexane (1:1 v/v). Fraction SA2 contains the aromatic hydrocarbons and chlorinated pesticides:PCBs. The PCBs and pesticides are separated using silica gel column chromatography. The elution patterns of the PCB's and pesticides in the silica gel columns were pre-determined using the standards. Sample extracts transferred to the previously standardized silica gel column

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will be eluted with hexane and will contain PCBs, HCB, Aldrin, heptachlor and 4,4'-DDE. The second fraction eluted with 20% methylene chloride in hexane will contain all other pesticides. The first and second fraction extracts were concentrated to 1 ml and 1 µl is injected into the gas chromatograph equipped with electroncapture detector (ECD). Capillary columns DB-5 and DB-1701 will be used for PCBs and pesticide analysis, respectively.

The pesticides:PCBs are analyzed by high-resolution fused silica capillary gas chromatography with electron capture detection (Hewlett Packard 5890 and Varian 3400CX). A capillary column 30 m long and 0.2 mm (inside diameter) with 0.25 µm thick DB-5 film is used with temperature programing from 40° to 300°C. Pesticides are identified and quantitated by comparison to authentic pesticide standards. PCB congeners of the same degree of chlorination are quantitated in comparison to a single reference congenerer described by NOAA (MacLeod *et al.*, 1985). To confirm the identification of PCBs and pesticides we use a second column, e.g. DB-17. If necessary, full scan gas liquid chromatography/mass spectrophotometry is used for any compounds where identification is questionable and compared with the mass spectrum of the authentic standards. The mass spectrometer operating conditions have been described above. Limits of detection for each compound are determined using authentic standards. Quality assurance procedures are similar to those described for the PAH work described above.

The GC-ECD method is validated in Table 6 by comparison of historical values with certified pesticides and PCB congeners.

6.8 Butyltins

The procedures used for butyltins are modified from those used in NOAA's National Status and Trends Program (Krone *et al.*, 1989).

To 10 g. of freeze-dried sediment in a round, bottom flask, is added 75 ml of methanol and 1 ml of 6N HCl. The mixture is boiled under reflux for 30 minutes using a water bath. After cooling to room temperature, 10 ml of a saturated NaCl solution is added and samples are spiked with 100 ml of the internal standard, tripropyltin chloride (275 ng Sn/50ml) in methanol. One hundred ml of hexane/tropolone (0.3 g/liter) is added to each sample and samples are shaken for 1 hour.

Samples are then centrifuged for 30 minutes at 2000 X g on a Sorval centrifuge. The upper organic layer is removed and reduced to 1.0 ml using a rotary evaporator. The organic phase is adjusted to 10 ml in hexane and butyltins are derivatized with 3 ml of Grignard reagent (2.0M hexymagnesium bromide) for 6 hours. Four ml of a 1:1 mixture of 6N HCl and water are then added to neutralize remaining Grignard reagent. The organic fraction is collected and the aqueous phase is extracted twice with hexane. The organic layer is concentrated to 2 ml in a concentrator tube. To purify the hexylated organotin compound, the 2 ml are passed down a column containing 12 g of alumina and 8 g of silica gel. The column is eluted with 50 ml of hexane. The hexane fraction is concentrated to 2.0 ml in a concentrator (K-D) tube.

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Concentration to final volume (0.1 ml) is done under nitrogen. Samples were analyzed by gas chromatography on a Hewlett Packard 5790 gas chromatography equipped with a DB-5 column and a flame photometric detector. The GC temperature was programmed from 60 C, at a rate of 12° C/min, to a final temperature of 300° C with a hold time of 10 min. The injector temperature was 300° C and the detector temperature was 250° C. A 610nm filter was used in the flame photometric detector. TBT, DBT, and MBT were determined with respect to tripropyltin, added as an internal standard.

To test extraction efficiency, the tributyltin, dibutyltin and monobutyltin are spiked into sediment samples to give concentrations from 5 to 200 ppb. The measured concentrations will be corrected for background levels of the butyltin and the results plotted against the spiked concentrations.

7.0 Data reduction, validation and reporting

7.1 ICP/MS data reduction

a)   It is the responsibility of the analyst to maintain properly identified records (hardcopies/diskettes) for possible reevaluation. Each data set analyzed by the ICP/MS is assigned a file name. This filename is placed on all records pertaining to the data set through all laboratory operations.

b)   All of the raw data from the ICP-MS is stored on magnetic media (5-1/4" HD, floppy diskettes). These diskettes are archived for possible reevaluation.

c)   Calibration of the standard curves are done by least squares regression methods which are stored in a computer. The operator of the ICP-MS can override the computer regression if necessary (i.e., one of the data points is outside acceptable limits).

d)   Sample concentrations in ng/ml or μ/ml are generated on an ASCII file.

e)   Reagent blank concentrations are evaluated for reproducibility. It is essential to blank correct the sample data in order to remove contributions from the acids used for digesting the samples and possible airborne contamination. All reagent blank concentrations will be reported in a final Q/A report.

f)   The ASCII data file produced in 8.1.d is processed through LOTUS-123 to make final calculations. These calculations include blank correction, dilution factors, sample volume and sample weight. The equation for the calculation is given below.

$$\text{Concentration (ppm)} = \frac{\text{ng/ml x dilution factors x volume - Blank}}{\text{Sample weight (mg)}}$$

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g)   A hard copy of the finished data is made for final Q/A review as well as an ASCII file for direct updating of a database.

7.2 GC/MS and GC data reduction

a)   PAH calibration curves (3-5 points) are constructed during sample runs using injections of varying amounts of perdeuterated standards covering the concentration range found to be present in samples. Similarly, pesticide and PCB congener curves using authentic standards are constructed during sample runs. Calibration curves will be constructed by computer using peak areas versus concentration.
b)   Reagent blank concentrations are evaluated for reproducibility. All reagent blank concentrations will be reported in a final Q/A report.

c)   The final calculations will be calculated by computer relative to calibration curves. These calculations include blank correction, dilution factors, sample volume and sample weight. PAH and chlorinated hydrocarbon concentrations will be expressed on a dry weight of sediment basis.

d)   A hard copy of the finished data is made for final Q/A review and will be turned over to project director for generation of the final report.

7.3 CHN Analyzer

a)   Raw data from the CHN analyzer is in (mv) microvolts.

b)   By normalizing the mv of the sample to the standard as shown below, the mg of carbon in the sample is determined.

$$\text{ug carbon} = \frac{\text{uv (sample)}}{\text{uv/mg (standard)}}$$

7.4 Data validation

a)   The hard copy of the data produced in section 8.1.f and 8.2.c is examined by the laboratory director or QA officer. This person is responsible for the integrity of the raw data and calculations, logs and internal chain of custody.

b)   The metals data is evaluated for accuracy of the certified standards (NIST 1646 and 1643C) and compared with the Q/A objectives table in Section 3.0. The organic data is validated by evaluating the accuracy of certified standards and/or internal standards.

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c)   The sample data is reviewed for precision of replicate analyses.

d)   Recovery of spiked samples is evaluated.

e)   It is the duty of the respective analysts (i.e., organics, inorganics, CHN, etc.) to verify that the data meets the Q/A objectives stated in the Q/A objective table in section 3.0.It is also their responsibility to maintain and properly archive all records for possible future re-evaluation of the data if required by the Q/A officer.

f)   It is also the responsibility of the Q/A officer to verify that the data meets the stated Q/A objectives. If these objectives are not met, the Q/A officer may require a re-evaluation of the data and/or re-analysis.

7.5 Data reporting

a)   The sample data is stored on a database management system (DBASE IV). The database is updated electronically from the ASCII files produced in 7.1.f. and 7.2.c.

b)   Reports are generated through the database report generator.

c)   The reports are reviewed by the Q/A Officer and the Contract Manager.

d)   The data is also available in DBASE IV, Lotus and ASCII formats.

8.0 Laboratory quality control checks

8.1 ICP/MS

a)   There are three types of quality control checks which are monitored for ICP/MS analysis.

b)   A Q/C standard (NIST 1643C) is analyzed at the beginning of the sample run and at a frequency of every 10 samples. This Q/C standard is monitored for overall instrument performance (i.e., continuing calibration standard).

c)   NIST (1646) sediment standard is analyzed at least twice during each sample run. Each of the two analyses are from separate sample digestions. This allows an evaluation of accuracy and precision and includes the variability in sample digestion.

d)   At least 5% of the samples will be spiked prior to sample digestion to evaluate possible matrix

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effects.

e)   At least two reagent blanks are prepared per sample set (approximately 20-25 samples). These reagent blanks are processed exactly as samples and the blank concentrations reported in the final Q/A report.

8.2 GC/MS

The quality control checks which are monitored for GC/MS analysis as follows:

a)   A perdeuterated-PAH standard mixture is analyzed at the beginning of each batch of samples. This Q/C standard is monitored for overall instrument performance.

b)   Each batch of 4 samples is accompanied by a spiked blank to check on reagents and procedures. These reagent blanks are processed exactly as samples and the blank concentrations reported in the final Q/A report.

c)   HS-6 sediment standard (National Research Council of Canada) is analyzed twice during each batch of analyses. This allows an evaluation of accuracy and precision and includes the variability in sample digestion.

d)   Each sample is spiked with a perdeuterated-PAH standard mixture prior to extraction to determine recovery and matrix effects.

8.3 GC

The quality control checks which are monitored for GC analysis are as follows:

a)   A 4,4-dibromooctofluorobiphenyl standard is analyzed at the beginning of each batch of samples. This Q/C standard is monitored for overall instrument performance.

b)   A standard mixture of pesticides and PCB congeners is analyzed twice during the analysis.

c)   All samples are spiked with 4,4-dibromooctofluorobiphenyl to evaluate recoveries and matrix effects.

d)   A reagent blank is prepared for each batch of samples (5 samples). These reagent blanks are processed exactly as samples and the blank concentrations reported in the final Q/A report.

8.4 CHN Analyzer

If the uv/mg of the standard acetanalide is not within specifications as outlined by the manufacturer the instrument must be recalibrated. Also, the blank must be within specifications.

9.0 Performance audit

a)   At least annually we participate in intercalibration exercises or assists in certification of standard reference material. These programs are run by International Council for the Exploration of the Seas (ICES), Intergovernmental Oceanographic Commission/United Nations Educational, Scientific and Cultural Organization (ICES/UNESCO), United Nations Environmental Program (UNEP) and the National Research Council of Canada.

10.0 Preventive maintenance

Major instruments are covered by service contracts. Routine maintenance schedules as suggested by equipment manufacturers are followed. The presence of backup equipment (e.g. several atomic absorption spectrophotometers) will allow for the continuation of work in the case of lengthy unscheduled down time.

10.1 ICP-MS (The following procedures are performed as outlined in VG Plasma Quad System manual. A daily log of the procedures is maintained.)

a)   Clean cones daily

b)   Clean torch, nebulizer and sample chamber daily

c)   Check resolution and mass calibration daily

d)   Clean lens stack every six months or as needed

e)   Adjust multiplier gain as needed.

10.2 GC/MS and GC

The following procedures are performed:

a)   Clean mass spectrometer source daily

b)   Tune and calibrate mass spectrometer daily

c) Adjust GC daily

10.3 Analytical balance

a) A service contact is maintained on all of the balances, which includes annual maintenance and inspections.

b) Clean pans and compartment daily

c) Check alignment and balance before use.

d) Daily check accuracy using certified weights.

e) Service contractor (see A above) is called if certified weights are not within $\pm 3.0\%$.

10.4 CHN

a) Maintain a clean environment around the instrument

b) Change combustion tube as needed

c) Check the instrument calibration daily

11.5 Miscellaneous Equipment

a) Ovens - A daily temperature check is made on the laboratory ovens when in use.

b) Freezers - daily temperature check.

11.0 Procedures to assess data precision, accuracy and completeness.

Procedures to assess data quality are the same for all parameters. Generic methods are discussed below.

11.1 Precision

Because of possible inhomogeneity in the samples, precision will be evaluated using replicate analyses of standard reference materials. Replicate analyses of standard reference materials will be made with each batch of samples.

The standard deviation of these replicate analyses will be determined:

$$s = \left(\left(\sum_{i=1}^{n} (x_1 - x)^{2} \right) / n \right)^{1}$$

where s is the standard deviation, n is the number of replicates, x is the mean of the replicates and x1 is the result for replicate i. The standard deviation should fall within the limits specified in the QA Objectives Table. Precision objectives listed in Section 3.0 were derived from results of replicate analyses of standard reference materials in this laboratory.

11.2 Accuracy

Accuracy will be assessed using standard reference materials. Spiked samples will not be used for reasons outlined in section 9.5 above. Standard reference materials will be digested and analyzed with each batch of samples. Percent recovery will be calculated for each analysis:

$$\%R = \frac{X-T}{T} \times 100$$

where X is the analysis result and T is the certified value. Also 5% of the samples will be spiked in order to evaluate possible matrix effects on spike recovery.

11.3 Completeness

95% or more of sample analyses will be completed.

12.0 Corrective action

If the standard deviation of the replicate analyses of the standard reference material does not meet the precision objectives outlined in the QA Objectives Table (Section 3.0), or if the recovery of the standard reference material is less than the accuracy listed in Section 3.0, corrective action will be initiated.

The first corrective action to be initiated will be a reanalysis of the sample run to determine if changes in instrument calibration or operation are responsible for the degradation in data quality. If the results of the second analysis remain outside of the limits of data acceptability, then the second action will be initiated. This action involves redigestion and analysis of the sample, with accompanying standard reference materials and blanks.

The QA officer shall monitor data quality and initiate any necessary corrective action.

APPENDIX A

Mercury Method

Determination of Mercury in Environmental Samples by Isotope Dilution/ICPMS

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The application of isotope dilution inductively coupled plasma mass spectrometry for the determination of mercury in sediment and water samples using an enriched ^{201}Hg spike is described. Sediment samples are determined directly after spiking with ^{201}Hg and a 1-h acid digestion. The procedural detection limit is 2 ng/g using a 0.5-g sample. Quantitative recovery is obtained on NRC reference standard (BEST-1), which is certified at 92 ± 9 ng/g. Natural levels of mercury in water samples require preconcentration onto gold traps and subsequent electrothermal heating and purging of the traps with argon directly into the torch of the ICPMS. The procedural detection limit is 0.2 ng/L using a 200-mL sample. The accuracy of the method was evaluated using a river water standard (ORMS-1) from the National Research Council of Canada, certified at 6.8 ± 1.3 ng/L. Results using this technique yield a value of 6.3 ± 0.4 ng/L.

INTRODUCTION

The toxicity of mercury in the environment has been well established. While there have been many different analytical techniques developed over the last two decades, the technique with the most widespread usage has been cold vapor atomic absorption. Improvements in the technique such as preconcentration onto gold traps and subsequent purging into an absorbance cell of an atomic absorption system or other measuring devices have helped to improve detection limits.[1-4] Also, the use of cold vapor atomic fluorescence for the determination of mercury species in natural samples has been reported.[5,6]

The emergence of inductively coupled plasma mass spectrometry (ICPMS) over the past 10 years has resulted in a multitude of technique papers. Recently, a compiled bibliography containing 152 references to publications on ICPMS techniques was reported.[7] However, specific applications to mercury determination in natural samples have been few. The direct determination of mercury in drinking water by ICPMS using direct injection nebulization (DIN) has recently been reported.[8] The method has a detection limit of 30 ng/L, which may not be suitable when accurate determinations of concentrations in natural waters approaching 1 ng/L are needed. The use of ICPMS for the cold vapor determination of mercury in natural samples using calibration curve

(1) Bloom, N. S.; Crecelius, E. A. *Mar. Chem.* 1983, *14*, 49–59.
(2) Dalziel, J. A.; Yeats, P. A. *Mar. Chem.* 1985, *15*, 357–361.
(3) Fitzgerald, W. F.; Gill, G. A. *Anal. Chem.* 1979, *51*, 1714–1720.
(4) Gill, G. A.; Fitzgerald, W. F. *Mar. Chem.* 1987, *20*, 227–243.
(5) Bloom, N.; Fitzgerald, W. F. *Anal. Chim. Acta* 1988, *208*, 151–161.
(6) Bloom, N. *Can. J. Aquat. Sci.* 1989, *46*, 1131–1140.
(7) McLaren, J. W. *Atom. Spectrosc.* 1992, *13*, S1–S8.
(8) Powell, M. J.; Quan, E. S. K.; Boomer, D. W. *Anal. Chem.* 1992, *64*, 2253–2257.

Table I. Instrument Parameters

mass range	200.4–204.9
number of channels	512
number of scan sweeps	600/400[a]
dwell time (μs)	160
collector type	pulse
skipped mass regions	202.6–204.9
isotopes selected	^{201}Hg, ^{202}Hg
nebulizer flow (L/min)	0.7

[a] Sediment: 600 scans, 49 s (aquisition time). Water: 400 scans, 33 s (aquisition time).

comparison and the capability of isotope dilution techniques was reported.[9] The reported instrument time required per sample is 10 min. A general review of isotope dilution mass spectrometry was done by Fasset and Paulsen.[10]

The work described in this paper represents a significant improvement over earlier reports on the determination of mercury in natural samples using ICPMS. Details on the determination of mercury in sediment and water using isotope dilution techniques are presented. Detection limits are comparable with other techniques and less than 1 min of instrument time is required per sample. The optimal spiking ratios of $^{202}Hg/^{201}Hg$ for the best accuracy and precision are reported. An unexpected loss of sensitivity in sediment analyses associated with purge time is also reported.

EXPERIMENTAL SECTION

Instrumentation. The inductively coupled plasma mass spectrometer used in this work is a Fisons Model PQII+ equipped with a standard interface and oil diffusion pumps. The modifications to the instrument include replacement of the glass elbow between the torch and the sample chamber with a short 12/2-mm ball and socket fitting. This fitting is connected with a $^5/_{16}$-in. Teflon elbow which reduces to a $^1/_8$-in. tube fitting. Teflon tubing ($^1/_8$ in.) is used between the Teflon elbow and the sample input source via a $^1/_8$–$^1/_4$-in. Teflon connector. Also the nebulizer supply is detached from the torch box and fitted with an extra length of tubing and a $^1/_4$-in. Teflon connector for mating with the sample purge input. The operating conditions used for data collection are shown in Table I.

The instrument is tuned before the above input modifications are made, using an aqueous tuning solution, and the tuning is rechecked about every 3 days. The mass calibration and resolution are also checked each time the instrument is tuned. The importance of proper mass calibration and resolution when ions with adjacent masses such as ^{201}Hg and ^{202}Hg are measured is obvious.

Reagents. Baker Instra-Analyzed nitric and hydrochloric acids are used without further purification. A 5% solution of sodium borohydride is made in a 0.1% KOH solution. This solution is purified by purging with nitrogen overnight at a flow rate of 200 mL/min. A 10% solution of stannous chloride is prepared in 3% H_2SO_4, and the solution is purified by purging with nitrogen at 200 mL/min overnight.

(9) Haraldsson, C.; Westerlund, S.; Ohman, P. *Anal. Chim. Acta* 1989, *221*, 77–84.
(10) Fassett, J. D.; Paulsen, P. J. *Anal. Chem.* 1989, *61*, 643A–649A.

TABLE 1.

INSTRUMENT STANDARDS

Instrument	Standard Source	How Received	Storage	Preparation	Labstock Storage	Frequency
ICP-MS	Commercial Supplier	1000 ppm	Room Temp	Stock Solutions (1-10 ppm) are diluted from source standard	1% HNO_3	Monthly
				Working Standards (1 ppb-1 ppm)	1% HNO_3	Daily
Carbon Analyzer	Commercial Lab Supplies	Solid	Room Temp	Weighed Into Sampling Boat (10 mg)		Daily
GC-MS	Commercial Lab Supplies	1 ppm	Freezer Temp	Stock Solution (1-10 ppb) are diluted from source standard	Octane	Daily
GC	Commercial Lab Supplies	1 ppm	Room Temp	Stock Solution (1-10 ppb) are diluted from source standard	Isoctane	Daily

TABLE 2.

INSTRUMENT CALIBRATIONS

Instrument	# Standard Initial Calib.	Acceptance/Rejection Criteria	Frequency	#Standards Cont. Calib.	Acceptance/Rejection Criteria	Frequency
ICP-MS	4	Linear regression correlation coef. of >0.99	Daily prior to use or failure of cont. calibration	1	Concentration must be within 10% of correct value	Initial and every 10 samples
Carbon Analyzer	1	must be within 5% of correct value	Daily	1	must be within 5% of accepted value	Initial and every 10 samples
GC-MS	2	Linear regression correlation coef. of >0.99	Daily prior to use	1	Concentration must be within 10% of correct value	Initial and every 4 samples
GC	2	Linear regression correlation coef. of >0.99	Daily prior to use	1	Concentration must be within 10% of correct value	Initial and every 5 samples

TABLE 3.

CALIBRATION PROTOCOL

1. ICP-MS

A) Initial tuning of the ion lenses is performed using a 100 ppb tuning solution. A test scan is made with the tuning solution in order to evaluate the mass calibration and resolution. Adjustments are made if necessary according to manufacturer's recommendations.

B) Sequence of events for initial calibration:
    a) Run blank solution (quartz distilled water with 1% HNO_3)
    b) Run all four standards
    c) Verify initial calibration
    d) Run Q/C standard (NIST 1643C) - must be within 10% of true value for acceptance
    e) Analyze 10 samples (includes reagent blanks, certified standard (NIST 1646), spikes and duplicates
    f) Run blank solution
    g) Run Q/C standard

C) Final Acceptance/Rejection. A certified sediment standard (NIST 1646) is analyzed periodically throughout the sample run. Concentrations of these standards must meet Q/A objectives in section 3.0.

2. GC/MS

A) Tuning is performed with calibration standards. Adjustments are made if necessary according to manufacturer's recommendations.

B) Sequence for initial calibration:
    a) Run blank (isooctane)
    b) Run 2 standards
    c) Verify calibration
    d) Run Q/C standard (deuterated PAH standard mixture) - must be within 10% of true value for acceptance
    e) Analyze 10 samples (includes reagent blanks, standard mixture, spikes and duplicates
    f) Run blank
    g) Run Q/C standard

C) Final Acceptance/Rejection. A certified sediment standard (HS-6-NRCC) is analyzed periodically during analysis. Concentrations of these standards must meet Q/A objectives in Section 3.0.

TABLE 3 (continued).

CALIBRATION PROTOCOL

3. GC

A) Sequence of events for calibration:
  a) Run blank (isooctane)
  b) Run four standards
  c) Run Q/C standard (mixture of PCB congeners - pesticides) - must be within
     10% of true value for acceptance
  d) Analyze ten samples (includes reagent blanks, standard mixture, spikes and
     duplicates)
  e) Run blank
  f) Run Q/C standard

B) Final Acceptance/Rejection. A sediment standard is analyzed periodically throughout the
   sample run. Concentrations of these standards must meet Q/A objectives in Section 3.0.

4. CHN Analyzer

    Calibration is initially performed by running a series of unweighed standards, blanks and
weighed standards. The sequence of the calibration is as follows:
  a) Run unweighed standard (acetanalide) for conditioning the instrument
  b) Run a blank (aluminum foil)
  c) Run unweighed standard
  d) Run blank
  e) If the blanks are within specification then run weighed standard (acetanalide)
  f) If instrument output ($\mu v/\mu g$) is within specification then begin
     running samples. If not, return to a).

Table 4

HISTORICAL VALUES FOR NIST 1646 OBTAINED BY ICP/MS

Sample	Aluminum (%)	Barium (ppm)	Cadmium (ppm)	Chromium (ppm)	Copper (ppm)	Iron (%)	Lead (ppm)	Lithium (ppm)	Manganese (ppm)	Phosphorous (%)	Nickel (ppm)	Silver (ppm)	Titanium (%)	Vanadium (ppm)	Zinc (ppm)	Mercury (ppb)
Rep1	6.33	380	0.37	74	19	3.21	26.5	47	353	0.058	29.7	0.37	0.46	97	132	92.4
Rep2	5.70	400	0.39	70	18	3.10	26.3	43	353	0.063	30.0	0.48	0.46	89	125	99.0
Rep3	5.37	376	0.31	71	19	3.04	23.9	49	350	0.058	28.5	0.31	0.45	94	129	98.6
Rep4	5.37	377	0.43	79	19	3.02	26.1	53	355	0.066	31.1	0.43	0.42	105	150	92.0
Rep5	6.50	398	0.37	81	21	3.37	31.3	48	360	0.061	28.5	0.31	0.42	94	127	101
Rep6	6.56	352	0.33	78	20	3.75	29.9	49	400	0.060	33.0	0.31	0.43	95	144	93.8
Rep7	5.91	340	0.43	87	22	3.35	28.3	55	372	0.065	37.6	0.31	0.40	100	166	93.9
Rep8	6.60	401	0.42	70	22	3.66	28.9	55	419	0.070	31.9	0.31	0.41	94	129	94.9
Rep9	6.95	417	0.48	77	20	3.67	30.0	56	360	0.070	30.9	0.35	0.40	88	147	92.4
Rep10	6.21	357	0.41	65	20	3.37	24.2	51	355	0.063	27.0	0.29	0.39	90	133	95.6
Rep11	5.69	380	0.43	66	20	3.39	26.9	49	330	0.055	26.0	0.29	0.40	90	138	95.8
Rep12	6.64	377	0.49	78	22	3.41	26.5	48	321	0.050	36.6	0.36	0.39	89	153	93.9
Rep13	6.34	389	0.47	75	21	3.32	27.4	47	372	0.045	35.6	0.28	0.38	91	142	95.8
Rep14	5.65	366	0.31	85	22	2.95	25.3	55	348	0.069	29.0	0.28	0.38	96	125	100
Rep15	5.95	375	0.47	79	22	3.07	25.7	53	350	0.061	30.7	0.27	0.37	100	130	93.4
Rep16	5.98	415	0.43	74	20	3.06	28.2	41	348	0.068	26.7	0.31	0.38	89	132	94.6
Rep17	5.88	400	0.37	74	22	3.28	27.4	42	341	0.060	32.1	0.33	0.40	94	131	95.0
Rep18	6.27	402	0.44	72	16	3.41	31.8	50	354	0.056	28.4	0.31	0.47	80	120	98.8
Rep19	6.31	405	0.47	67	17	3.21	30.7	59	355	0.061	30.9	0.33	0.49	92	127	92.0
Rep20	5.80	377	0.49	74	18	3.08	27.1	54	393	0.066	29.5	0.27	0.50	93	133	96.0
Rep21	6.24	385	0.45	79	20	3.05	27.2	55	347	0.068	31.9	0.29	0.55	98	132	98.0
Rep22	6.16	385	0.39	67	20	3.61	28.0	46	350	0.056	26.1	0.37	0.50	91	130	94.3
Rep23	6.25	380	0.35	71	18	3.50	28.2	49	360	0.050	28.1	0.32	0.47	94	135	95.0
Mean	6.12	384	0.41	74	20	3.30	26.5	50	359	0.061	30.4	0.33	0.43	92	135	95.0
S. Dev	0.41	19	0.06	6	2	0.23	5.5	5	21	0.007	3.1	0.05	0.05	9	11	3.0
NIST 1646	6.25 ±0.20		0.36 0.07	76 3	18 3	3.35 0.10	28.2 1.8	(49)	375 20	0.054 0.005	32 3		(0.51)	88 10	138 6	92 9

BEST-1 (National Research Council of Canada)

TABLE 5

IONS TO DETERMINE PAH ANALYTES

Compound	Ret. Time	Characterization Ions Used
Naphthalene	3.23	128
Naphthalene-d_8	3.23	136
Acenaphthylene	5.25	152
Acenaphthene-d_{10*}	5.53	164
Acenaphthene	5.58	154
Fluorine	6.61	166
Phenanthrene-d_{10*}	9.0	188
Phenanthrene	9.06	178
Anthracene	9.19	178
Fluoranthene	12.92	202
Pyrene	13.65	202
Benzo(a)anthracene	18.19	228
Chrysene-d_{12}	18.20	240
Chrysene	18.28	228
Benzo(b)fluoranthene	21.98	252
Benzo(k)fluoranthene	22.07	252
Benzo(e)pyrene	22.84	252
Benzo(a)pyrene	22.99	252
Perylene-d_{12*}	23.19	264
Perylene	23.20	252
Indeno(2,3,4-cd)pyrene	26.39	276
Dibenz(a,h)anthracene	26.50	278
Benzo(g,h,i)perylene	27.06	276

*Internal standard used to monitor GC/MS system performance and determine surrogate compound recovery.

TABLE 6

HISTORICAL VALUES FOR PAHs IN HS-6
OBTAINED BY GC/MS (units - µg/g)

Sample	Phenanthrene	Fluorene	Benzo(a)pyrene	Anthracene	Fluoranthene	Indeno(1,2,3-cd)pyrene	Benzo(b)Fluoranthrene	Benzo(k)Fluoranthrene	Benzo(a)anthracene
Rep 1	2	0.8	2.9	1.9	3.1	2.5	3.5	1.1	1.5
Rep 2	4	1.0	3.5	0.7	3.0	1.2	3.7	1.5	1.9
Rep 3	5	0.5	2.7	1.1	2.7	2.7	2.0	0.9	2.5
Rep 4	4	0.6	2.4	1.7	3.7	2.1	2.5	1.9	2.2
Rep 5	3	0.4	2.0	1.2	4.0	3.0	3.6	2.0	1.1
Rep 6	3	0.5	2.6	0.9	1.9	2.0	4.0	1.5	1.7
Rep 7	5	0.4	2.2	1.0	2.7	1.5	2.1	1.7	2.0
Mean	4	0.6	2.6	1.2	3.0	2.6	2.8	1.5	1.8
S. Dev.	±1.1	±0.2	±0.5	±0.5	±0.7	±0.8	±0.8	±0.4	±0.5
HS 6	3±0.6	0.5±0.1	2.2±0.4	1.1±0.4	3.5±0.7	2.0±0.6	2.8±0.6	1.4±0.2	1.8±0.3

TABLE 7

HISTORICAL VALUES FOR PESTICIDES AND PCBs IN IAEA-357
OBTAINED BY GC/ECD (units - ng/g)

Sample	P,P'-DDE	P,P'-DDD	P,P'-DDT	Heptachlor	PCB-28	PCB-44	PCB-52	PCB-101	PCB-105	PCB-118	PCB-128	PCB-138	PCB-170
Rep 1	25	27	32	0.9	13	17	41	69	27	107	9	59	11
Rep 2	27	35	55	2.1	12	25	50	65	25	79	12	87	17
Rep 3	34	29	37	2.3	16	19	51	80	30	85	10	90	15
Rep 4	38	28	45	0.8	15	18	45	77	28	97	13	75	14
Rep 5	26	36	59	2.0	16	24	47	70	33	88	8	85	12
Rep 6	30	32	30	1.6	14	22	52	72	30	103	18	69	
Rep 7	31	30	60	1.0	14	25	49	66	29	95	14	76	18
Rep 8	27	29	55	0.9	12	25	50	70	31	87	16	82	17
Mean	30	31	39	1.5	14	22	48	71	29	93	13	78	15
S. Dev	±4	±3	±12	±0.6	±2	±3	±4	±5	±3	±10	±4	±10	±3
IAEA 7	32±7	32±6	46±12	1.5±0.6	14±4	22±4	47	73±6	29	92	15	74±16	15±5

APPENDIX II.

Radionuclide Data

All activities in dpg/m

M = data not collected

NSTC

depth	$^{210}Pb_{total}$	^{226}Ra	$^{210}Pb_{xs}$	^{137}Cs
0.50	7.52	3.64	3.88	0.51
1.50	8.04	3.03	5.01	0.50
2.50	7.07	2.86	4.21	0.35
3.50	6.67	2.87	3.80	0.49
4.50	7.27	3.07	4.20	0.31
5.50	7.32	3.04	4.29	0.45
6.50	8.60	3.00	5.59	0.47
7.50	9.40	3.18	6.23	0.47
8.50	9.38	3.08	6.30	0.59
10.50	9.93	2.59	7.34	0.56
11.50	7.30	2.33	4.98	0.40
12.50	5.83	2.41	3.41	0.25
13.50	6.56	2.56	4.00	0.38
14.50	8.05	2.63	5.42	0.49
15.50	10.34	2.88	7.47	0.66
16.50	9.33	2.87	6.45	0.70
17.50	8.96	3.09	5.87	0.42
18.50	5.48	2.44	3.04	0.40
19.50	5.09	1.98	3.11	0.33
20.50	6.62	2.41	4.21	0.41
21.50	7.24	2.49	4.75	0.37
22.50	7.64	2.85	4.79	0.45
23.50	9.62	2.66	6.97	0.50
24.50	9.73	2.80	6.93	0.63
25.50	8.76	2.75	6.01	0.41

26.50	7.50	2.53	4.97	0.38
28.50	9.77	2.87	6.90	0.53
29.50	10.45	2.99	7.46	0.55
30.50	10.88	2.87	8.01	0.63
31.50	11.08	2.81	8.27	0.63
32.50	10.73	2.85	7.88	0.72
33.50	8.87	2.73	6.14	0.47
34.50	7.03	2.54	4.49	0.39
35.50	7.96	2.36	5.61	0.36
36.50	7.72	2.46	5.26	0.37
37.50	8.93	2.80	6.14	0.53
38.50	9.69	2.86	6.83	0.51
39.50	9.64	2.76	6.88	0.50
40.50	9.52	2.70	6.82	0.56
41.50	9.31	2.60	6.71	0.52
42.50	8.41	2.79	5.62	0.44
43.50	0.89	0.27	0.62	0.05
44.50	10.29	1.76	8.53	0.19
45.50	10.64	2.95	7.69	0.69
46.50	10.52	2.80	7.72	0.71
47.50	8.63	2.95	5.68	0.70
48.50	9.27	2.87	6.40	0.59
49.50	7.81	2.68	5.13	0.49
50.50	7.35	2.44	4.91	0.43
51.50	7.52	2.64	4.88	0.48

NSTE

depth	Cumulative Dry Mass (g/cm^2)	$^{210}Pb_{total}$	^{226}Ra	$^{210}Pb_{xs}$	^{137}Cs
0.50	0.37	9.84	3.94	5.84	0.88
4.50	1.26	9.92	3.30	6.68	0.59
7.50	2.26	9.63	3.17	6.28	0.63
10.50	3.25	10.63	3.43	6.86	0.65
13.50	4.18	11.72	3.88	8.28	0.95
15.50	5.24	11.04	5.49	5.33	0.41
20.50	6.91	M	M	3.36	0.00
26.50	8.83	6.61	2.86	3.39	0.00
29.50	10.53	4.87	2.96	1.86	0.00
32.50	12.19	5.61	2.96	2.37	0.00
37.50	14.14	4.35	3.32	1.03	0.00
42.50	16.49	4.19	2.63	1.57	0.00
48.50	19.16	3.96	2.87	1.01	0.00
54.50	22.04	3.68	2.28	1.45	0.00

NSTF

depth	Cumulative Dry Mass (g/cm^2)	$^{210}Pb_{total}$	^{226}Ra	$^{210}Pb_{xs}$	^{137}Cs
1.00	0.47	6.62	1.24	5.40	0.26
5.50	1.43	6.61	1.58	5.04	1.65
8.50	2.22	5.72	1.60	4.14	2.49
9.50	2.66	5.46	1.78	3.74	2.83
10.50	3.04	5.24	1.42	3.89	2.36
12.50	3.65	5.14	1.51	3.65	1.82
15.50	4.76	4.59	1.68	2.92	1.54
21.50	6.58	4.12	1.79	2.33	0.69
27.50	9.13	3.72	1.78	1.94	0.46
36.50	12.11	3.56	1.96	1.60	0.32
42.50	15.24	2.91	1.80	1.12	0.00
51.50	18.62	2.61	2.15	0.46	0.00

NSTG

depth	Cumulative Dry Mass (g/cm²)	²¹⁰Pb$_{total}$	²²⁶Ra	²¹⁰Pb$_{xs}$	¹³⁷Cs
1.00	0.6600	8.79	2.02	6.79	0.79
5.50	2.0157	8.66	2.13	6.54	0.78
9.50	3.2880	7.98	1.66	6.33	0.73
12.50	4.3274	6.95	1.64	5.34	0.85
13.50	M	M	M	M	0.87
14.50	M	M	M	M	0.84
15.50	5.0907	6.32	1.55	4.80	1.08
16.50	5.6399	6.46	1.65	4.88	0.81
18.50	6.2907	5.55	1.88	3.69	0.78
21.50	7.2326	4.74	1.87	2.88	0.49
24.50	8.3408	4.54	1.89	2.70	0.55
27.50	9.5159	4.38	1.73	2.65	0.42
30.50	10.7565	3.71	1.81	1.94	0.29
33.50	12.0731	3.97	2.03	1.98	0.22
36.50	13.5224	3.98	2.23	1.76	0.15
39.50	15.1187	3.52	1.85	1.70	0.03
42.50	16.8132	3.54	2.24	1.31	0.05
45.50	18.6624	3.10	2.01	1.11	0.07
48.50	20.5529	3.05	2.01	1.04	0.00
51.50	22.3520	3.18	2.13	1.05	0.00

NSTH

depth	Cumulative Dry Mass (g/cm^2)	^{210}Pb$_{total}$	^{226}Ra	^{210}Pb$_{xs}$	^{137}Cs
0.50	0.89	8.83	1.93	6.98	1.14
10.50	3.17	8.30	1.93	6.44	1.34
19.50	6.04	7.11	1.97	5.20	1.55
29.50	9.06	6.63	1.99	4.71	1.65
36.50	12.04	6.45	2.12	4.40	1.25
44.50	16.84	6.89	2.46	4.51	2.00
62.50	26.94	6.70	2.33	4.42	2.42
82.50	M	5.50	M	M	4.89
87.50	M	6.24	M	M	7.50
92.50	41.36	5.44	2.25	3.23	7.35
97.50	M	5.14	M	M	3.03
102.50	M	4.64	M	M	1.77
112.50	M	4.60	M	M	0.29
122.50	56.42	4.65	2.32	2.35	0.04
152.50	71.78	4.80	2.63	1.91	0.00
182.50	86.36	4.40	2.53	1.89	0.00
205.00	99.28	4.30	2.76	1.57	0.02
225.00	114.06	4.20	2.91	1.31	0.03
260.00	133.84	3.95	2.56	1.41	0.07
300.00	155.39	4.08	2.64	1.46	0.00
330.00	176.07	4.34	3.20	1.14	0.05
370.00	201.54	4.00	2.91	1.11	0.00
430.00	231.31	3.80	2.76	1.06	0.03
470.00	259.77	3.98	3.00	0.98	0.00
520.00	287.78	4.01	2.64	1.39	0.00

APPENDIX III

Concentrations of Si, C, N, $CaCO_3$ in Cores C, E, F, G, H, L and M

Sample	Depth (cm)	Silicon %	Carbon %	Nitrogen %	Carbonate %
C-0	0-1	26.3	2.62	0.22	4.85
C-01	1-2	25.5	3.24	0.28	7.03
C-02	2-3	22.5	3.75	0.31	13.38
C-03	3-4	23.2	3.74	0.32	7.76
C-04	4-5	23.9	3.04	0.31	12.78
C-05	5-6	23.9	2.99	0.30	12.12
C-06	6-7	23.2	3.55	0.35	13.14
C-07	7-8	24.1	3.11	0.31	12.67
C-08	8-9	27.6	1.60	0.16	8.49
C-09	9-10	28.4	1.69	0.16	6.73
C-10	10-11	28.3	2.42	0.24	9.89
C-11	11-12	25.1	2.74	0.27	7.44
C-12	12-13	23.3	3.28	0.31	13.87
C-13	13-14	24.2	3.00	0.28	13.02
C-14	14-15	23.8	3.16	0.32	14.02
C-15	15-16	23.5	3.71	0.35	10.07
C-16	16-17	23.3	3.68	0.35	11.80
C-17	17-18	24.5	2.84	0.31	9.94
C-18	18-19	25.1	2.63	0.22	10.39
C-19	19-20	27.7	2.44	0.20	6.87
C-20	20-21	24.9	2.47	0.22	8.27
C-21	21-22	23.0	3.16	0.30	12.70
C-22	22-23	26.5	2.84	0.28	9.18
C-23	23-24	23.7	4.66	0.32	7.44
C-24	24-25	22.7	3.53	0.34	11.18
C-25	25-26	24.7	3.59	0.32	9.86
C-26	26-27	28.6	2.58	0.21	4.23
C-27	27-28	30.3	1.89	0.17	5.43
C-28	28-29	28.0	2.61	0.17	8.26
C-29	29-30	26.4	3.37	0.27	8.21
C-30	30-31	23.6	3.59	0.28	8.84
C-31	31-32	26.1	3.23	0.28	7.16
C-32	32-33	25.4	3.08	0.26	8.14
C-33	33-34	27.3	2.98	0.24	9.08
C-34	34-35	28.5	1.95	0.17	5.28
C-35	35-36	27.2	3.07	0.28	10.34
C-36	36-37	23.9	3.25	0.32	10.51
C-37	37-38	24.3	3.04	0.32	10.08
C-38	38-39	24.5	3.42	0.32	9.91
C-39	39-40	25.4	2.86	0.26	7.83
C-40	40-41	25.3	2.22	0.21	9.14
C-41	41-42	24.4	2.67	0.26	9.96
C-42	42-43	23.6	2.54	0.23	9.98
C-43	43-44	23.1	3.29	0.32	9.28
C-44	44-45	22.6	3.27	0.27	11.60
C-45	45-46	24.4	2.71	0.26	8.76
C-46	46-47	24.1	2.71	0.25	11.00
C-47	47-48	23.3	3.35	0.32	10.97
C-48	48-49	23.0	3.81	0.35	10.42
C-49	49-50	22.6	3.24	0.30	9.92
C-50	50-51	22.5	3.14	0.34	10.55
C-51	51-52	23.3	2.97	0.29	6.81
C-52	52-53	25.3	3.12	0.29	10.86

NOAA Sediments
Core-C

Sample	Depth (cm)	Silicon %	Carbon %	Nitrogen %	Carbonate %
C-53	53-54	24.8	3.24	0.28	8.87
C-54	54-55	27.2	3.14	0.29	8.18
C-55	55-56	27.6	3.31	0.30	8.06
C-56	56-57	26.7	3.04	0.27	7.46

Sample	Depth (cm)	Silicon %	Carbon %	Nitrogen %	Carbonate %
E-01	0-1	20.0	3.94	0.29	10.04
E-02	1-2	29.7	3.13	0.26	6.80
E-03	2-3	27.7	3.56	0.29	8.33
E-04	3-4	27.5	3.54	0.32	9.58
E-05	4-5	21.9	3.62	0.30	8.76
E-06	5-6	29.0	3.44	0.19	7.49
E-07	6-7	28.0	3.36	0.28	7.26
E-08	7-8	28.0	3.23	0.24	7.87
E-09	8-9	22.3	2.96	0.28	11.53
E-10	9-10	27.8	2.84	0.22	13.24
E-11	10-11	28.6	3.01	0.23	11.32
E-12	11-12	24.4	2.68	0.23	21.37
E-13	12-13	29.5	1.36	0.11	11.43
E-14	13-14	23.8	2.67	0.22	10.41
E-15	14-15	30.4	2.50	0.19	11.99
E-16	15-16	32.7	2.14	0.18	6.25
E-17	16-17	30.5	2.46	0.16	11.99
E-18	17-18	30.7	2.15	0.16	8.40
E-19	18-19	29.7	2.47	0.15	8.89
E-20	19-20	22.3	2.92	0.21	8.88
E-21	20-21	30.1	2.45	0.14	15.21
E-22	21-22	35.3	2.05	0.16	6.88
E-23	22-23	29.8	1.72	0.15	13.56
E-24	23-24	31.4	1.73	0.13	7.11
E-25	24-25	32.8	1.55	0.13	2.47
E-26	25-26	29.7	1.73	0.14	6.01
E-27	26-27	39.7	1.31	0.10	1.77
E-28	27-28	34.4	1.93	0.18	3.22
E-29	28-29	38.8	1.52	0.13	3.33
E-30	29-30	38.0	1.59	0.13	3.61
E-31	30-31	35.8	1.44	0.13	3.62
E-32	31-32	24.7	2.00	0.17	7.91
E-33	32-33	35.5	1.81	0.14	5.21
E-34	33-34	31.4	2.11	0.17	4.47
E-35	34-35	32.1	1.55	0.14	5.22
E-36	35-36	31.6	1.82	0.16	7.43
E-37	36-37	29.6	1.90	0.16	6.40
E-38	37-38	21.7	1.79	0.16	10.53
E-39	38-39	28.5	1.90	0.17	5.63
E-40	39-40	27.1	1.91	0.16	5.70
E-41	40-41	29.2	2.02	0.20	6.52
E-42	41-42	26.6	2.01	0.18	13.48
E-43	42-43	25.2	2.04	0.19	9.05
E-44	43-44	20.4	1.93	0.18	10.21
E-45	44-45	25.3	1.94	0.15	14.12
E-46	45-46	28.4	2.10	0.18	7.81
E-47	46-47	26.2	2.10	0.18	9.26
E-48	47-48	25.4	2.14	0.19	11.95
E-49	48-49	25.1	2.09	0.17	12.68
E-50	49-50	19.1	2.16	0.19	10.99
E-51	50-51	27.7	2.21	0.20	7.33
E-52	51-52	27.7	2.05	0.16	6.92
E-53	52-53	27.7	2.19	0.21	6.76

Sample	Depth (cm)	Silicon %	Carbon %	Nitrogen %	Carbonate %
E-54	53-54	25.0	2.02	0.17	12.56
E-55	54-55	19.8	2.29	0.20	9.38
E-56	55-56	27.4	2.29	0.20	14.64
E-57	56-57	24.9	2.36	0.20	6.18
E-58	57-58	28.7	1.98	0.15	6.48

NOAA Sediments
Core-F

Sample	Depth (cm)	Silicon %	Carbon %	Nitrogen %	Carbonate %
F-01	0-1	17.0	11.00	0.54	6.90
F-02	1-2	23.4	13.56	0.69	5.86
F-03	2-3	16.7	12.77	0.63	8.00
F-04	3-4	24.4	10.00	0.66	4.39
F-05	4-5	17.8	10.91	0.62	5.62
F-06	5-6	24.3	11.34	0.63	3.46
F-07	6-7	26.1	9.24	0.59	1.28
F-08	7-8	25.4	10.06	0.62	2.45
F-09	8-9	25.3	7.79	0.51	4.57
F-10	9-10	26.7	8.24	0.53	3.61
F-11	10-11	25.1	6.95	0.44	4.02
F-12	11-12	26.0	9.69	0.52	5.83
F-13	12-13	18.6	7.25	0.43	5.82
F-14	13-14	26.3	7.33	0.48	4.20
F-15	14-15	26.4	6.51	0.44	1.03
F-16	15-16	26.4	6.99	0.45	1.72
F-17	16-17	26.8	7.23	0.44	2.37
F-18	17-18	27.0	5.86	0.41	3.86
F-19	18-19	27.1	5.59	0.36	4.36
F-20	19-20	25.8	5.99	0.37	4.79
F-21	20-21	18.5	5.44	0.33	4.82
F-22	21-22	25.6	5.91	0.36	4.65
F-23	22-23	24.6	6.01	0.41	4.36
F-24	23-24	24.5	5.64	0.39	5.45
F-25	24-25	25.2	4.57	0.31	3.31
F-26	25-26	26.1	4.03	0.30	2.60
F-27	26-27	26.1	4.66	0.22	2.53
F-28	27-28	25.9	4.03	0.31	3.53
F-29	28-29	18.7	4.33	0.29	5.81
F-30	29-30	24.7	4.72	0.33	4.60
F-31	30-31	24.6	4.28	0.29	2.76
F-32	31-32	24.7	4.27	0.33	4.28
F-33	32-33	24.8	3.43	0.28	3.93
F-34	33-34	25.0	3.59	0.29	4.33
F-35	34-35	24.1	3.64	0.30	4.71
F-36	35-36	24.8	3.52	0.27	2.59
F-37	36-37	17.3	3.51	0.28	5.54
F-38	37-38	23.6	3.51	0.27	4.08
F-39	38-39	23.9	3.66	0.29	3.88
F-40	39-40	22.5	3.45	0.28	4.38
F-41	40-41	22.4	3.74	0.28	6.21
F-42	41-42	21.8	3.94	0.26	7.00
F-43	42-43	22.1	4.99	0.35	5.04
F-44	43-44	22.4	4.23	0.30	5.86
F-45	44-45	16.1	4.17	0.29	6.12
F-46	45-46	22.0	4.34	0.30	4.88
F-47	46-47	22.7	3.63	0.26	5.10
F-48	47-48	22.3	4.10	0.28	5.33
F-49	48-49	22.3	4.11	0.29	4.77
F-50	49-50	22.8	3.63	0.28	3.44
F-51	50-51	22.7	3.65	0.28	5.02
F-52	51-52	16.4	3.88	0.27	6.16
F-53	52-53	24.2	3.77	0.26	5.51

NOAA Sediments
Core-F

Sample	Depth (cm)	Silicon %	Carbon %	Nitrogen %	Carbonate %
F-54	53-54	24.0	3.29	0.25	5.25
F-55	54-55	24.2	3.45	0.28	4.35

NOAA Sediments
Core-G

Sample	Depth (cm)	Silicon %	Carbon %	Nitrogen %	Carbonate %
G-01	0-1	22.4	5.84	0.42	7.52
G-02	1-2	24.7	4.78	0.38	18.77
G-03	2-3	25.0	4.87	0.39	17.99
G-04	3-4	27.8	5.91	0.46	6.50
G-05	4-5	25.4	5.08	0.43	11.43
G-06	5-6	21.1	5.51	0.42	5.08
G-07	6-7	27.8	5.03	0.41	6.65
G-08	7-8	27.5	5.78	0.43	6.33
G-09	8-9	26.9	5.61	0.43	5.98
G-10	9-10	20.1	6.02	0.43	5.44
G-11	10-11	27.9	6.26	0.42	6.77
G-12	11-12	26.2	5.46	0.41	6.45
G-13	12-13	26.1	5.84	0.43	6.64
G-14	13-14	26.0	5.86	0.41	7.53
G-15	14-15	26.0	5.82	0.42	7.68
G-16	15-16	26.9	5.06	0.36	8.42
G-17	16-17	18.9	5.22	0.37	4.71
G-18	17-18	25.8	5.42	0.37	5.30
G-19	18-19	25.8	5.32	0.37	5.23
G-20	19-20	25.7	4.57	0.33	5.70
G-21	20-21	26.0	4.50	0.32	5.94
G-22	21-22	24.9	4.65	0.33	6.63
G-23	22-23	25.5	4.11	0.29	5.34
G-24	23-24	25.1	3.97	0.30	6.15
G-25	24-25	18.4	4.60	0.33	5.29
G-26	25-26	24.6	4.30	0.31	5.79
G-27	26-27	25.0	3.99	0.22	6.44
G-28	27-28	24.1	3.55	0.27	5.87
G-29	28-29	23.1	3.80	0.27	6.56
G-30	29-30	25.0	3.58	0.26	5.91
G-31	30-31	25.1	3.49	0.25	6.48
G-32	31-32	23.8	3.18	0.24	5.26
G-33	32-33	18.3	2.98	0.24	5.74
G-34	33-34	25.4	2.90	0.24	4.28
G-35	34-35	25.4	2.64	0.22	5.52
G-36	35-36	25.2	2.33	0.20	5.44
G-37	36-37	25.0	2.26	0.19	5.58
G-38	37-38	25.1	2.25	0.19	3.55
G-39	38-39	25.8	2.07	0.19	4.83
G-40	39-40	24.7	1.98	0.17	4.74
G-41	40-41	18.2	2.03	0.20	5.30
G-42	41-42	23.9	1.91	0.17	3.60
G-43	42-43	24.7	2.10	0.19	4.61
G-44	43-44	24.3	2.02	0.18	4.13
G-45	44-45	24.5	2.11	0.19	4.14
G-46	45-46	23.6	1.93	0.18	5.17
G-47	46-47	24.8	1.98	0.17	5.02
G-48	47-48	24.5	1.99	0.19	5.35
G-49	48-49	18.9	2.03	0.19	4.84
G-50	49-50	24.0	1.93	0.18	4.69
G-51	50-51	24.0	1.96	0.18	5.86

NOAA Sediments
Core-H

Sample	Depth (cm)	Silicon %	Carbon %	Nitrogen %	Carbonate %
H-0	0-1	23.4	7.07	0.55	2.29
H-019	19-20	22.6	7.29	0.51	1.04
H-039	39-40	25.4	3.84	0.30	1.07
H-060	60-65	24.1	4.29	0.32	2.91
H-080	80-85	23.2	3.93	0.30	3.75
H-100	100-105	23.4	4.04	0.27	1.32
H-120	120-125	22.3	3.09	0.27	4.34
H-135	135-140	22.9	2.81	0.24	3.08
H-160	160-165	22.1	2.56	0.22	2.28
H-180	180-185	22.6	3.34	0.20	1.62
H-200	200-210	22.9	1.87	0.18	5.40
H-230	230-240	21.2	1.63	0.16	4.92
H-255	255-265	21.5	1.81	0.19	4.29
H-325	325-335	20.2	1.39	0.17	4.58
H-395	395-405	21.6	2.44	0.22	5.05
H-465	465-475	20.4	1.33	0.14	4.77
H-515	515-525	21.3	1.86	0.19	4.75

NOAA Sediments
Core-L

Sample	Depth (cm)	Silicon %	Carbon %	Nitrogen %	Carbonate %
L1-01-2	1-2	24.5	2.09	0.18	6.71
L1-06-7	6-7	24.7	2.64	0.22	3.79
L1-10-11	10-11	24.4	2.27	0.18	4.97
L1-15-16	15-16	23.8	2.00	0.20	8.57
L1-20-21	20-21	23.6	2.36	0.22	6.33
L1-25-26	25-26	24.2	2.20	0.18	4.16
L1-30-31	30-31	24.2	2.38	0.19	4.27
L1-35-36	35-36	23.8	2.64	0.21	4.14
L1-40-41	40-41	24.0	3.87	0.22	4.93
L1-45-46	45-46	23.9	2.56	0.21	4.86

NOAA Sediments
Core-M

Sample	Depth (cm)	Silicon %	Carbon %	Nitrogen %	Carbonate %
M-01	0-1	31.4	0.58	0.04	10.36
M-02	1-2	32.2	0.50	0.05	9.37
M-03	2-3	33.0	0.62	0.05	8.53
M-04	3-4	33.4	0.61	0.06	9.65
M-05	4-5	29.9	1.03	0.08	12.12
M-06	5-6	28.1	1.21	0.10	12.83
M-07	6-7	29.5	1.36	0.13	11.92
M-08	7-8	30.5	0.86	0.08	11.18
M-09	8-9	31.2	0.82	0.06	9.44
M-10	9-10	31.3	0.44	0.07	9.30
M-11	10-11	31.4	0.73	0.05	9.30
M-12	11-12	31.7	1.01	0.09	10.17
M-13	12-13	31.6	1.03	0.08	10.42
M-14	13-14	30.7	1.02	0.08	10.59
M-15	14-15	31.3	0.97	0.08	11.19
M-16	15-16	30.9	1.26	0.11	10.58
M-17	16-17	31.7	1.30	0.10	10.39
M-18	17-18	29.5	1.72	0.12	9.90
M-19	18-19	30.2	1.87	0.17	9.69
M-20	19-20	28.2	1.79	0.13	9.55
M-21	20-21	28.5	2.21	0.17	10.40
M-22	21-22	27.5	2.06	0.16	11.52
M-23	22-23	27.0	2.38	0.19	12.32
M-24	23-24	27.0	2.24	0.18	12.25
M-25	24-25	26.1	2.18	0.19	11.56
M-26	25-26	26.0	2.28	0.21	12.01
M-27	26-27	27.9	1.80	0.17	11.90
M-28	27-28	26.3	1.94	0.14	12.44
M-29	28-29	26.4	2.36	0.19	13.06
M-30	29-30	26.6	2.51	0.21	11.05
M-31	30-31	28.0	1.76	0.15	11.13
M-32	31-32	27.5	1.78	0.13	10.67
M-33	32-33	30.2	1.72	0.13	10.23
M-34	33-34	29.4	1.46	0.11	10.17
M-35	34-35	29.3	1.79	0.15	11.07
M-36	35-36	29.3	1.89	0.17	10.24
M-37	36-37	30.5	1.78	0.15	9.87
M-38	37-38	29.7	1.69	0.13	11.45
M-39	38-39	29.2	1.78	0.14	11.35
M-40	39-40	28.4	2.03	0.19	11.78
M-41	40-41	29.0	2.42	0.19	11.71
M-42	41-42	32.4	1.98	0.15	10.32
M-43	42-43	31.5	1.45	0.12	8.73
M-44	43-44	32.3	1.88	0.14	8.47
M-45	44-45	32.2	1.61	0.13	9.43
M-46	45-46	31.5	1.83	0.16	8.96
M-47	46-47	32.2	1.28	0.11	9.51
M-48	47-48	33.4	1.05	0.08	9.02
M-49	48-49	32.2	1.07	0.08	8.84
M-50	49-50	32.0	1.10	0.08	9.01
M-51	50-51	30.5	1.36	0.12	8.89
M-52	51-52	30.2	1.79	0.14	9.61
M-53	52-53	30.0	1.75	0.14	9.52

APPENDIX IV.

Concentrations of Metals in Cores C, E, F, G, H, L, and M

NOAA Sediments
Core-C

Sample	Depth (cm)	Aluminum %	Arsenic ppm	Cadmium ppm	Chromium ppm	Copper ppm	Iron %	Lead ppm	Manganese ppm	Mercury ppb	Nickel ppm	Phosporus ppm	Silver ppm	Selenium ppm	Antimony ppm	Tin ppm	Zinc ppm
C-0	0-1	6.24	13.6	0.10	74.9	19.0	3.17	28.3	521	69	25.0	913	0.28		0.16	1.94	96
C-01	1-2	8.23	20.5	0.18	52.9	14.6	4.34	20.0	428	95	16.2	854	0.09	0.85	0.55	2.71	75
C-02	2-3	9.35	14.6	0.19	86.7	27.1	4.46	30.0	680	99	23.0	1,196	0.19	0.85	0.42	3.20	101
C-03	3-4	9.23	10.3	0.17	68.5	18.4	4.72	26.2	503	109	22.0	875	0.17	0.69	0.52	3.12	92
C-04	4-5	9.28	16.0	0.19	85.2	26.1	4.52	28.4	746	99	26.2	1,156	0.21	0.67	0.41	3.46	102
C-05	5-6	9.01	17.1	0.16	84.5	24.4	4.47	26.3	775	91	21.8	1,076	0.17	0.68	0.33	2.74	101
C-06	6-7	9.08	18.4	0.17	85.3	26.0	4.61	27.0	819	91	22.5	1,068	0.20	0.50	0.39	3.29	102
C-07	7-8	9.15	16.1	0.17	85.9	22.3	4.62	25.6	868	91	24.2	1,102	0.17	0.60	0.38	3.19	102
C-08	8-9	7.30	18.3	0.14	73.8	20.8	3.68	23.6	687	78	19.2	976	0.16	0.63	0.32	2.48	87
C-09	9-10	6.48	26.6	0.11	58.9	15.3	3.53	13.7	546	82	17.6	488	0.10	0.64	0.34	2.24	83
C-10	10-11	8.07	17.3	0.16	73.6	22.2	4.02	31.0	651	90	21.0	888	0.18	0.69	0.38	2.77	82
C-11	11-12	8.81	24.9	0.16	74.1	20.1	4.75	28.5	655	119	23.8	962	0.15	0.76	0.35	2.28	96
C-12	12-13	9.18	16.7	0.20	84.9	25.7	4.72	29.3	801	112	23.6	1,130	0.22		0.49	3.28	96
C-13	13-14	9.17	21.2	0.19	84.3	26.1	4.97	31.4	927	121	34.3	1,106	0.20	0.69	0.50	3.17	105
C-14	14-15	8.98	18.6	0.18	82.2	23.8	4.93	31.4	935	122	22.4	1,229	0.19		0.36	3.13	108
C-15	15-16	9.11	22.7	0.19	76.8	24.2	5.24	35.1	812	130	23.2	1,363	0.19	0.98	0.51	2.73	120
C-16	16-17	9.28	15.4	0.19	84.4	25.9	4.82	34.1	635	136	20.5	1,258	0.21		0.50	3.25	101
C-17	17-18	9.28	19.2	0.18	85.8	25.3	4.75	33.0	697	118	22.6	1,243	0.21	0.67	0.49	3.42	100
C-18	18-19	8.37	15.6	0.17	78.6	21.5	4.33	29.9	645	117	20.7	1,338	0.19		0.43	2.92	89
C-19	19-20	7.78	6.9	0.12	61.2	18.3	3.74	28.2	541	105	18.8	1,132	0.11	0.81	0.32	1.92	89

NOAA Sediments
Core-C

Sample	Depth (cm)	Aluminum %	Arsenic ppm	Cadmium ppm	Chromium ppm	Copper ppm	Iron %	Lead ppm	Manganese ppm	Mercury ppb	Nickel ppm	Phosporus ppm	Silver ppm	Selenium ppm	Antimony ppm	Tin ppm	Zinc ppm
C-20	20-21	7.99	13.8	0.17	73.6	22.5	3.94	27.8	541	95	18.8	1,057	0.20		0.38	2.88	87
C-21	21-22	9.27	19.6	0.22	84.8	24.0	4.62	32.6	556	112	42.7	1,106	0.23	0.62	0.47	3.59	96
C-22	22-23	8.89	15.1	0.20	79.6	24.7	4.40	30.8	555	100	23.3	1,109	0.19		0.38	2.93	93
C-23	23-24	9.37	12.8	0.17	78.3	23.7	4.63	35.3	556	111	26.0	1,232	0.20	0.89	0.68	2.81	106
C-24	24-25	9.19	17.6	0.22	85.3	26.8	4.50	32.7	570	106	29.4	1,301	0.21		0.42	3.55	100
C-25	25-26	9.00	12.0	0.19	83.7	25.3	4.34	32.1	549	102	23.7	1,247	0.19	0.40	0.39	3.26	98
C-26	26-27	5.92	8.1	0.12	47.8	13.8	2.88	21.3	360	65	15.3	862	0.16		0.47	2.31	72
C-27	27-28	5.27	8.1	0.11	50.0	14.2	2.75	18.1	355	64	13.1	758	0.12	0.40	0.21	1.88	57
C-28	28-29	7.13	15.0	0.15	66.0	19.0	3.94	23.2	442	76	18.9	1,002	0.16		0.32	2.52	77
C-29	29-30	7.55	13.8	0.14	71.1	19.7	4.11	24.9	468	83	20.1	997	0.17	0.58	0.31	2.55	80
C-30	30-31	7.97	16.9	0.17	77.2	22.1	3.95	27.5	500	80	21.2	1,049	0.18		0.35	2.77	86
C-31	31-32	7.65	16.9	0.17	82.7	22.2	4.64	26.8	557		25.9	1,166	0.20	0.49	0.44	2.42	107
C-32	32-33	7.03	14.9	0.13	66.7	19.3	3.31	24.2	446		20.7	949	0.15		0.28	2.32	74
C-33	33-34	8.67	17.5	0.20	83.1	25.1	3.95	31.2	503		23.6	1,157	0.20	0.33	0.40	3.47	98
C-34	34-35	7.16	11.8	0.13	57.9	16.1	3.51	22.6	398		18.4	904	0.13		0.45	2.45	86
C-35	35-36	8.39	16.7	0.13	76.4	22.6	3.70	27.3	464		21.5	1,067	0.15	0.40	0.38	2.74	94
C-36	36-37	9.27	16.7	0.18	84.8	25.1	4.06	30.1	514		24.1	1,273	0.21		0.44	3.38	102
C-37	37-38	9.66	16.2	0.17	90.1	27.0	4.32	32.4	548		25.1	1,458	0.19		0.43	3.39	112
C-38	38-39	9.34	16.0	0.16	86.2	26.3	4.23	30.8	540		25.5	1,454	0.20		0.42	3.29	114

NOAA Sediments
Core-C

Sample	Depth (cm)	Aluminum %	Arsenic ppm	Cadmium ppm	Chromium ppm	Copper ppm	Iron %	Lead ppm	Manganese ppm	Mercury ppb	Nickel ppm	Phosporus ppm	Silver ppm	Selenium ppm	Antimony ppm	Tin ppm	Zinc ppm
C-39	39-40	8.91	16.7	0.15	73.5	22.5	4.73	33.9	506		25.3	1,302	0.16		0.53	3.45	120
C-40	40-41	8.37	16.7	0.16	81.5	24.4	4.01	27.5	526		23.1	1,242	0.22		0.37	2.88	101
C-41	41-42	8.54	17.3	0.17	83.3	25.5	4.01	28.2	524		23.4	1,152	0.20		0.39	2.96	100
C-42	42-43	8.11	16.2	0.16	78.5	22.4	3.85	26.7	498		22.6	1,116	0.21		0.39	2.99	91
C-43	43-44	8.90	11.3	0.12	75.5	21.4	4.80	24.2	516		25.4	984	0.16		0.50	2.74	105
C-44	44-45	8.83	18.5	0.17	90.9	24.3	3.80	28.8	556		25.2	1,062	0.21		0.37	2.96	94
C-45	45-46	8.77	23.4	0.13	73.9	22.1	4.42	26.1	548		25.4	1,200	0.14		0.48	2.98	99
C-46	46-47	9.16	16.6	0.17	82.3	26.0	3.72	26.8	556		24.0	1,243	0.21		0.37	3.05	103
C-47	47-48	9.33	19.7	0.16	87.1	24.5	3.92	28.4	547		25.6	1,251	0.21		0.42	3.19	114
C-48	48-49	9.62	19.5	0.18	91.1	27.6	4.25	29.1	559		27.0	1,320	0.19		0.43	3.21	109
C-49	49-50	10.16	16.1	0.18	93.5	27.5	4.39	26.4	551		27.8	1,306	0.21		0.41	3.29	109
C-50	50-51	9.86	16.3	0.18	92.9	27.0	4.10	29.7	529		27.1	1,285	0.21		0.45	3.44	105
C-51	51-52	9.77	12.8	0.15	75.3	22.3	4.81	38.0	485		25.5	1,044	0.14		0.49	3.09	106
C-52	52-53	9.79	16.8	0.19	89.6	26.3	3.98	32.1	497		26.1	1,168	0.22		0.44	3.39	99
C-53	53-54	9.35	18.6	0.18	84.3	24.6	3.76	30.9	481		23.7	994	0.21		0.39	3.15	93
C-54	54-55	9.00	12.4	0.20	81.4	24.1	3.70	29.3	467		23.0	1,012	0.21		0.37	3.00	93
C-55	55-56	8.80	14.5	0.19	81.3	23.5	3.84	28.8	479		21.5	993	0.21		0.38	3.03	90
C-56	56-57	9.12	16.9	0.19	85.5	24.2	3.83	30.1	486		24.4	1,016	0.21		0.36	3.02	93

NOAA Sediments
Core-E

Sample	Depth (cm)	Aluminum %	Arsenic ppm	Cadmium ppm	Chromium ppm	Copper ppm	Iron %	Lead ppm	Manganese ppm	Mercury ppb	Nickel ppm	Phosporus ppm	Silver ppm	Selenium ppm	Antimony ppm	Tin ppm	Zinc ppm
E-01	0-1	7.96	20.8	0.38	92.2	33.5	4.90	28.6	729	106	23.1	1,167	0.27	0.45	0.44	5.35	145
E-02	1-2	6.89	21.9	0.34	75.4	21.0	5.15	25.7	613	111	23.4	909	0.25		0.50	4.20	106
E-03	2-3	8.00	22.4	0.30	83.5	26.7	5.25	24.9	570	108	26.8	854	0.24	0.48	0.50	3.40	127
E-04	3-4	9.16	23.2	0.31	89.1	26.9	5.43	33.0	585	107	27.6	1,020	0.22		0.51	3.50	130
E-05	4-5	8.99	22.4	0.28	92.9	35.0	5.42	29.2	605	105	24.6	1,201	0.16	0.49	0.49	4.28	150
E-06	5-6	9.16	19.1	0.32	86.2	24.7	4.99	27.8	532	106	23.1	866	0.24		0.51	3.80	108
E-07	6-7	7.18	20.8	0.29	91.7	26.2	5.18	34.3	533	103	26.9	853	0.23	0.64	0.50	3.70	116
E-08	7-8	7.54	23.7	0.26	87.5	22.8	4.97	26.8	519	98	23.5	852	0.23		0.48	3.60	109
E-09	8-9	8.33	22.2	0.22	96.1	35.6	5.47	31.4	652	94	24.3	1,514	0.23	0.67	0.65	5.28	182
E-10	9-10	7.41	21.6	0.26	77.5	21.7	5.09	30.4	549	100	22.1	1,075	0.23		0.52	3.20	129
E-11	10-11	7.81	19.6	0.25	83.7	24.4	4.84	27.1	523	101	23.5	937	0.26	0.89	0.48	3.10	129
E-12	11-12	6.08	17.5	0.24	71.6	19.0	4.49	26.2	440	95	20.4	781	0.22		0.43	3.00	102
E-13	12-13	7.77	21.0	0.25	84.7	22.9	4.65	23.0	556	94	22.6	986	0.25	0.20	0.46	3.00	130
E-14	13-14	7.82	15.0	0.19	73.1	27.6	4.91	29.1	543	96	21.8	1,076	0.29		0.52	3.44	158
E-15	14-15	6.00	18.7	0.25	72.4	19.2	4.51	26.7	490	93	20.0	757	0.25	0.60	0.50	2.70	112
E-16	15-16	6.19	16.6	0.22	70.8	18.7	4.18	21.2	524	92	20.6	739	0.21		0.43	2.70	100
E-17	16-17	5.80	15.0	0.20	64.9	21.2	3.85	25.7	536	92	21.1	630	0.17	0.48	0.42	2.60	77
E-18	17-18	7.44	19.5	0.25	73.6	21.0	4.45	28.7	564	114	21.6	705	0.19		0.51	3.10	92
E-19	18-19	6.20	18.5	0.25	76.8	24.8	4.60	21.9	593	118	24.9	754	0.19	0.23	0.48	3.00	110
E-20	19-20	8.40	21.1	0.19	70.9	32.9	5.18	29.9	573	145	22.4	899	0.30		0.58	4.59	140

NOAA Sediments
Core-E

Sample	Depth (cm)	Aluminum %	Arsenic ppm	Cadmium ppm	Chromium ppm	Copper ppm	Iron %	Lead ppm	Manganese ppm	Mercury ppb	Nickel ppm	Phosporus ppm	Silver ppm	Selenium ppm	Antimony ppm	Tin ppm	Zinc ppm
E-21	20-21	5.81	17.2	0.29	77.8	24.5	3.86	33.7	545	97	22.6	737	0.18	0.44	0.42	2.50	98
E-22	21-22	5.51	9.8	0.17	62.3	20.4	3.47	29.7	495	73	20.7	574	0.14		0.39	2.20	72
E-23	22-23	6.70	12.0	0.20	74.2	25.4	3.79	35.6	658	108	24.3	723	0.15	0.42	0.47	2.90	84
E-24	23-24	8.32	16.3	0.28	81.5	28.0	4.74	37.4	723	125	27.2	881	0.22		0.65	3.80	86
E-25	24-25	5.30	11.1	0.17	59.1	19.1	2.98	29.0	517	100	18.9	544	0.14	0.41	0.43	2.40	59
E-26	25-26	8.05	14.2	0.12	62.6	31.0	4.24	30.0	597	94	20.0	767	0.22		0.60	3.99	90
E-27	26-27	5.40	9.7	0.13	51.6	16.9	2.62	28.2	501	91	16.6	502	0.12		0.36	2.10	41
E-28	27-28	6.20	11.7	0.28	60.9	21.3	3.20	30.5	571	105	21.9	540	0.14		0.43	2.50	49
E-29	28-29	6.60	11.9	0.18	63.3	22.2	3.52	33.3	608	104	21.6	583	0.14		0.51	3.00	64
E-30	29-30	4.50	9.5	0.13	47.5	16.3	2.48	25.3	425	94	16.2	446	0.12		0.44	2.20	36
E-31	30-31	7.31	8.4	0.19	73.2	24.3	3.97	36.3	695	132	25.0	670	0.17		0.57	3.20	66
E-32	31-32	8.36	15.2	0.13	68.1	33.4	4.09	31.4	615	117	24.3	828	0.20		0.61	4.90	98
E-33	32-33	9.33	14.3	0.22	81.5	27.6	4.21	40.0	716	162	27.9	523	0.19		0.63	3.80	76
E-34	33-34	8.91	14.4	0.22	79.7	27.1	4.47	42.2	693	162	26.2	652	0.19		0.60	3.70	66
E-35	34-35	8.93	16.4	0.22	76.3	24.7	4.39	35.6	804	137	24.8	695	0.17		0.56	3.60	65
E-36	35-36	9.83	15.4	0.23	84.2	29.6	4.78	42.0	569	144	27.4	696	0.18		0.61	4.00	73
E-37	36-37	10.13	16.1	0.24	93.4	34.7	5.31	42.7	828	155	34.5	852	0.17		0.66	4.20	90
E-38	37-38	11.17	21.0	0.32	77.4	44.0	5.61	38.1	1,068	134	29.4	1,051	0.12		0.71	5.31	117
E-39	38-39	13.22	16.0	0.24	87.8	30.9	5.74	41.2	758	163	32.9	798	0.18		0.73	4.50	80

NOAA Sediments
Core-E

Sample	Depth (cm)	Aluminum %	Arsenic ppm	Cadmium ppm	Chromium ppm	Copper ppm	Iron %	Lead ppm	Manganese ppm	Mercury ppb	Nickel ppm	Phosporus ppm	Silver ppm	Selenium ppm	Antimony ppm	Tin ppm	Zinc ppm
E-40	39-40	13.51	16.0	0.23	97.8	36.8	5.79	48.7	809	153	36.5	849	0.17		0.64	4.40	95
E-41	40-41	13.85	15.9	0.24	87.7	33.0	6.05	43.7	693	151	33.4	787	0.18		0.64	4.50	87
E-42	41-42	12.03	14.7	0.20	89.4	32.7	5.60	42.2	617	141	33.8	793	0.16		0.59	4.10	90
E-43	42-43	12.43	15.3	0.23	92.5	37.2	6.07	46.4	622	153	36.1	820	0.17		0.70	4.40	129
E-44	43-44	12.70	19.1	0.18	82.2	48.1	6.19	41.1	774	142	31.1	1,126	0.28		0.64	5.81	124
E-45	44-45	12.11	11.5	0.24	92.2	35.2	5.52	45.5	861	154	33.5	787	0.19		0.68	4.50	89
E-46	45-46	13.08	9.5	0.24	97.9	37.8	5.60	45.2	697	149	36.7	823	0.18		0.78	4.50	101
E-47	46-47	11.66	15.5	0.24	99.7	40.3	5.88	46.8	658	143	37.8	842	0.20		0.63	4.30	101
E-48	47-48	11.94	14.7	0.22	95.3	34.0	5.69	42.3	1,114	143	30.5	810	0.17		0.65	4.10	94
E-49	48-49	11.50	16.2	0.23	87.7	32.0	5.61	39.4	1,034	157	33.7	758	0.17		0.66	4.10	88
E-50	49-50	12.16	18.6	0.18	86.0	48.1	6.30	39.7	1,002	148	31.9	1,110	0.12		0.75	5.86	124
E-51	50-51	11.73	16.5	0.25	91.6	35.4	5.95	44.7	768	167	35.0	737	0.20		0.96	4.60	89
E-52	51-52	10.36	17.0	0.25	93.0	39.2	5.88	41.8	1,095	162	35.4	809	0.19		0.78	4.60	91
E-53	52-53	12.61	16.8	0.25	00.0	38.1	5.92	42.3	1,076	161	36.4	850	0.21		0.73	4.40	93
E-54	53-54	12.19	11.5	0.24	87.5	31.9	5.57	41.0	945	162	29.4	323	0.21		0.78	4.30	79
E-55	54-55	12.01	21.4	0.25	87.6	45.1	5.80	39.9	959	140	30.4	1,074	0.13		1.04	5.91	122
E-56	55-56	10.29	13.5	0.23	98.5	29.9	5.06	40.6	1,069	150	35.1	806	0.21		0.76	4.10	86
E-57	56-57	11.15	12.5	0.27	01.6	36.0	5.74	44.0	1,096	156	35.9	826	0.20		0.79	4.50	91
E-58	57-58	10.88	11.3	0.36	93.8	32.4	5.51	43.7	682	154	31.7	730	0.20		0.82	4.40	90

NOAA Sediments
Core-F

Sample	Depth (cm)	Aluminum %	Arsenic ppm	Cadmium ppm	Chromium ppm	Copper ppm	Iron %	Lead ppm	Manganese ppm	Mercury ppb	Nickel ppm	Phosporus ppm	Silver ppm	Selenium ppm	Antimony ppm	Tin ppm	Zinc ppm
F-01	0-1	6.49	12.5	0.13	68.1	30.5	2.70	27.8	193	107	16.5	791	0.24		0.56	3.12	97
F-02	1-2	7.71	12.6	0.15	89.9	22.5	2.46	19.9	153	118	21.7	814	0.19		0.82	3.20	104
F-03	2-3	7.17	9.1	0.16	76.7	30.1	2.45	25.7	117	115	20.7	678	0.18	0.45	0.60	2.83	83
F-04	3-4	7.95	12.3	0.13	95.1	20.4	2.55	26.1	124	156	21.5	617	0.19		1.22	3.40	66
F-05	4-5	8.28	11.8	0.25	06.6	32.4	2.75	36.8	116	173	18.8	807	0.23	0.58	0.61	3.31	87
F-06	5-6	10.20	12.6	0.12	26.4	23.9	2.85	37.2	134	213	24.1	725	0.16		1.13	3.60	87
F-07	6-7	10.55	13.3	0.13	33.4	25.1	2.97	42.1	140	221	25.3	772	0.18	0.46	1.28	3.70	82
F-08	7-8	8.88	12.1	0.12	32.3	26.3	2.82	42.1	143	174	25.3	741	0.16		0.96	3.40	88
F-09	8-9	10.03	11.5	0.12	34.6	25.3	3.13	41.6	145	156	26.7	737	0.16	0.24	0.80	3.50	84
F-10	9-10	10.07	13.0	0.13	35.8	28.3	3.16	46.4	159	175	29.0	803	0.19		0.78	3.70	88
F-11	10-11	10.70	10.6	0.11	24.3	26.2	3.06	45.4	147	166	25.8	657	0.15	0.31	0.64	3.30	82
F-12	11-12	10.74	13.3	0.14	26.4	28.3	3.01	44.3	153	169	27.4	681	0.20		1.09	4.00	83
F-13	12-13	9.88	12.8	0.10	23.3	39.1	3.01	38.1	139	145	25.1	708	0.17	0.40	0.55	3.53	96
F-14	13-14	10.57	12.6	0.13	16.3	28.0	3.13	41.4	144	165	24.4	549	0.20		0.69	4.10	81
F-15	14-15	10.61	12.3	0.11	11.9	27.7	3.09	43.5	143	170	26.6	655	0.19	0.38	1.30	3.50	86
F-16	15-16	9.02	13.7	0.15	07.3	26.5	3.13	42.3	139	157	27.6	604	0.20		1.26	3.60	83
F-17	16-17	11.65	17.0	0.18	94.2	25.0	3.05	37.4	123	157	25.4	533	0.22	0.33	1.18	4.00	77
F-18	17-18	11.71	18.3	0.17	13.8	30.8	3.25	42.8	153	161	33.7	704	0.21		1.25	4.00	98
F-19	18-19	14.30	23.9	0.23	97.4	28.8	3.78	46.9	138	158	31.0	579	0.20	0.37	0.87	3.80	94
F-20	19-20	11.72	25.8	0.27	07.7	34.9	3.91	51.6	158	147	37.7	648	0.20		0.99	3.50	127

NOAA Sediments
Core-F

Sample	Depth (cm)	Aluminum %	Arsenic ppm	Cadmium ppm	Chromium ppm	Copper ppm	Iron %	Lead ppm	Manganese ppm	Mercury ppb	Nickel ppm	Phosporus ppm	Silver ppm	Selenium ppm	Antimony ppm	Tin ppm	Zinc ppm
F-21	20-21	10.88	23.8	0.24	92.8	40.1	4.17	41.0	144	155	31.5	659	0.12	0.47	0.58	3.77	139
F-22	21-22	11.01	22.5	0.27	03.9	36.2	4.43	27.5	171	155	38.8	652	0.21		0.92	3.90	142
F-23	22-23	10.77	21.9	0.27	90.0	31.4	4.90	22.2	159	148	35.7	396	0.20	0.22	0.88	3.80	126
F-24	23-24	10.57	15.9	0.25	94.7	33.7	5.07	29.6	176	152	37.9	593	0.18		1.34	3.90	130
F-25	24-25	11.92	15.9	0.26	93.3	34.7	5.29	27.5	173	150	37.0	527	0.19	0.36	1.10	4.20	122
F-26	25-26	10.94	21.5	0.28	85.5	34.9	5.46	20.7	166	147	34.5	514	0.20		1.00	4.10	117
F-27	26-27	12.53	15.0	0.22	93.7	38.2	5.00	22.7	184	144	35.8	525	0.20	0.43	0.72	4.10	117
F-28	27-28	11.04	17.9	0.23	78.2	30.3	5.11	20.7	160	144	30.2	450	0.19		0.79	4.20	98
F-29	28-29	11.49	12.7	0.14	82.6	38.6	5.62	21.0	175	124	29.2	578	0.13	0.26	0.75	3.67	121
F-30	29-30	9.54	21.5	0.24	72.8	30.7	5.76	15.4	161	141	29.3	426	0.17		0.77	4.10	98
F-31	30-31	11.89	19.7	0.19	70.9	29.1	5.28	15.2	162	143	27.9	408	0.18	0.22	0.67	3.90	93
F-32	31-32	12.47	24.2	0.25	72.8	30.7	5.21	29.2	160	144	28.4	443	0.20		0.83	4.30	89
F-33	32-33	11.98	22.1	0.20	84.5	36.2	5.08	18.2	195	151	34.0	477	0.15		0.67	4.00	106
F-34	33-34	13.46	22.9	0.21	85.4	38.4	5.51	24.9	199	151	34.9	552	0.16		1.61	4.00	111
F-35	34-35	11.80	25.1	0.21	75.6	34.8	5.46	15.9	180	148	31.5	495	0.16		0.83	3.90	98
F-36	35-36	11.87	24.9	0.21	84.5	38.0	5.89	17.9	205	147	35.0	568	0.17		0.84	4.00	112
F-37	36-37	12.09	15.2	0.12	79.2	45.5	5.91	23.5	197	125	31.2	706	0.21		0.55	3.74	123
F-38	37-38	12.51	22.5	0.20	85.6	40.5	5.87	16.9	219	142	36.1	599	0.16		0.70	3.80	115
F-39	38-39	12.44	19.0	0.18	74.0	36.1	6.32	14.1	206	146	30.1	552	0.14		0.64	3.60	105

NOAA Sediments
Core-F

Sample	Depth (cm)	Aluminum %	Arsenic ppm	Cadmium ppm	Chromium ppm	Copper ppm	Iron %	Lead ppm	Manganese ppm	Mercury ppb	Nickel ppm	Phosporus ppm	Silver ppm	Selenium ppm	Antimony ppm	Tin ppm	Zinc ppm
F-40	39-40	12.32	25.3	0.20	79.9	38.1	6.43	18.0	220	142	33.7	574	0.16		0.72	3.80	113
F-41	40-41	11.99	25.2	0.19	74.5	36.6	6.43	17.0	215	145	31.6	565	0.15		0.62	3.60	105
F-42	41-42	11.36	27.2	0.20	73.3	35.7	7.24	17.9	219	140	30.6	557	0.16		0.67	3.70	103
F-43	42-43	10.92	27.6	0.19	72.7	35.5	7.51	18.9	223	143	31.0	520	0.17		0.66	3.60	103
F-44	43-44	11.76	26.1	0.17	81.0	39.8	6.97	16.6	258	149	35.3	601	0.16		1.42	3.40	116
F-45	44-45	10.73	15.2	0.21	68.4	44.5	7.25	27.7	227	130	29.4	707	0.20		0.46	4.43	116
F-46	45-46	11.93	25.9	0.17	79.0	40.7	6.96	16.0	279	143	34.4	612	0.16		0.80	3.40	116
F-47	46-47	10.93	20.4	0.16	76.1	38.4	7.10	15.8	298	146	34.1	566	0.15		0.67	3.60	110
F-48	47-48	11.08	20.8	0.17	71.7	37.1	6.96	18.5	295	153	32.1	505	0.17		0.62	3.50	107
F-49	48-49	11.14	18.0	0.16	70.2	36.8	6.77	16.6	297	150	30.2	510	0.15		0.63	3.40	105
F-50	49-50	12.99	18.6	0.16	71.1	35.3	6.80	18.2	290	159	30.5	710	0.16		0.60	3.40	89
F-51	50-51	11.28	19.7	0.14	70.3	35.6	5.87	13.8	279	160	29.1	676	0.15		0.52	3.10	87
F-52	51-52	11.76	14.4	0.27	69.7	46.0	6.00	18.4	300	131	30.3	681	0.28		0.61	3.39	118
F-53	52-53	11.42	23.2	0.16	70.0	34.8	5.54	14.0	281	159	30.0	658	0.17		0.72	3.50	92
F-54	53-54	10.70	23.9	0.14	69.5	34.6	5.62	16.3	282	153	30.7	639	0.16		0.57	3.30	90
F-55	54-55	10.74	22.5	0.15	73.3	36.8	5.36	16.6	291	155	32.9	708	0.18		0.60	3.50	94

NOAA Sediments
Core-G

Sample	Depth (cm)	Aluminum %	Arsenic ppm	Cadmium ppm	Chromium ppm	Copper ppm	Iron %	Lead ppm	Manganese ppm	Mercury ppb	Nickel ppm	Phosporus ppm	Silver ppm	Selenium ppm	Antimony ppm	Tin ppm	Zinc ppm
G-01	0-1	8.73	22.8	0.12	01.2	19.4	4.43	32.9	430	128	24.6	1,191	0.24	0.27	0.51	3.38	149
G-02	1-2	8.04	12.3	0.17	74.3	19.1	3.56	24.8	254	111	21.0	837	0.21		0.69	3.20	82
G-03	2-3	7.64	14.9	0.23	74.7	17.7	3.35	24.5	239	114	22.5	819	0.24	0.31	0.60	3.30	90
G-04	3-4	7.79	12.2	0.18	84.3	18.8	3.99	27.2	242	123	26.3	881	0.23		0.62	3.50	95
G-05	4-5	9.00	11.6	0.16	82.0	20.0	3.64	26.2	226	120	23.0	810	0.23	0.20	1.24	3.40	92
G-06	5-6	9.18	15.3	0.18	01.6	20.9	4.03	36.1	260	126	25.7	926	0.17		0.38	3.17	133
G-07	6-7	9.02	9.8	0.18	00.9	21.8	3.65	30.0	250	128	27.8	789	0.25	0.35	0.88	3.60	115
G-08	7-8	8.73	14.0	0.18	97.6	22.8	3.89	31.8	238	128	27.2	741	0.24		0.65	3.70	113
G-09	8-9	9.58	13.4	0.20	04.7	24.9	3.86	33.5	254	134	28.9	809	0.23	0.32	0.66	4.00	118
G-10	9-10	9.36	20.6	0.13	04.6	21.6	4.07	36.0	250	124	26.3	757	0.52		0.91	3.42	131
G-11	10-11	9.03	14.3	0.18	91.8	21.7	3.79	24.5	221	142	25.0	638	0.22	0.15	0.57	3.80	93
G-12	11-12	8.80	16.0	0.20	10.9	26.6	3.94	34.3	267	146	31.2	753	0.23		0.58	3.70	111
G-13	12-13	9.29	17.4	0.20	16.9	27.4	4.04	34.4	272	154	29.1	737	0.23	0.19	0.60	3.90	111
G-14	13-14	9.33	19.1	0.19	15.2	27.4	3.99	35.8	278	151	30.1	721	0.21		0.52	3.60	110
G-15	14-15	9.02	22.6	0.21	99.1	23.6	4.61	27.6	269	150	28.4	653	0.22	0.20	0.53	3.80	105
G-16	15-16	9.61	27.4	0.24	02.6	24.4	4.60	24.9	284	154	28.6	648	0.25		1.02	4.60	109
G-17	16-17	9.51	20.2	0.30	10.5	21.6	4.50	29.3	305	154	28.7	762	0.26		0.55	6.04	123
G-18	17-18	9.19	19.9	0.21	97.6	24.4	4.65	18.0	287	150	27.8	619	0.20	0.25	0.70	4.40	106
G-19	18-19	9.17	17.9	0.18	93.5	23.8	4.90	17.3	284	150	26.6	550	0.14	0.25	0.62	3.80	104
G-20	19-20	9.18	20.2	0.23	94.7	24.7	4.79	17.7	282	157	28.0	584	0.21		0.66	5.60	104

NOAA Sediments
Core-G

Sample	Depth (cm)	Aluminum %	Arsenic ppm	Cadmium ppm	Chromium ppm	Copper ppm	Iron %	Lead ppm	Manganese ppm	Mercury ppb	Nickel ppm	Phosporus ppm	Silver ppm	Selenium ppm	Antimony ppm	Tin ppm	Zinc ppm
G-21	20-21	9.88	17.4	0.19	94.9	25.1	5.34	16.9	292	164	28.5	555	0.16	0.26	0.55	4.50	107
G-22	21-22	10.39	17.7	0.21	99.0	27.4	5.40	17.7	314	161	30.9	641	0.19		0.60	4.20	113
G-23	22-23	10.05	12.8	0.21	93.2	25.1	5.04	17.6	302	164	28.9	603	0.14	0.14	0.64	4.60	109
G-24	23-24	9.40	13.7	0.21	96.4	27.6	5.61	18.5	321	165	30.5	624	0.13		0.60	4.20	111
G-25	24-25	10.53	19.5	0.18	01.2	23.0	5.91	20.4	319	153	28.5	671	0.14	0.10	0.57	3.64	124
G-26	25-26	9.90	9.9	0.22	80.5	24.7	5.78	15.3	307	148	28.2	502	0.12		0.57	4.00	100
G-27	26-27	10.32	20.7	0.26	84.6	27.1	5.80	16.5	335	150	29.8	579	0.23		0.81	4.50	106
G-28	27-28	10.38	15.3	0.22	80.3	26.2	5.59	15.9	334	151	28.1	568	0.15		0.76	4.60	100
G-29	28-29	9.83	21.7	0.25	80.8	26.2	5.45	21.3	339	143	28.7	572	0.20		0.94	5.40	98
G-30	29-30	10.29	22.4	0.23	83.0	28.1	5.71	22.3	376	145	29.7	627	0.20		0.91	4.70	106
G-31	30-31	10.87	14.9	0.19	77.9	26.6	5.43	18.8	372	145	29.2	586	0.16		0.69	4.50	99
G-32	31-32	10.83	15.3	0.21	75.5	27.2	5.56	18.5	401	145	30.2	602	0.14		0.69	5.50	99
G-33	32-33	11.79	15.9	0.30	94.9	26.3	6.06	20.2	456	148	32.3	713	0.41		0.55	4.07	135
G-34	33-34	10.89	14.7	0.20	74.0	28.3	5.54	21.0	420	141	30.4	599	0.17		0.66	4.60	99
G-35	34-35	11.04	10.1	0.18	74.2	29.5	5.68	18.5	440	142	31.6	656	0.07		0.61	4.50	104
G-36	35-36	11.08	11.1	0.18	75.8	30.4	6.02	20.5	476	139	32.8	660	0.11		0.64	5.00	106
G-37	36-37	10.60	12.4	0.20	81.0	34.1	6.07	20.4	531	140	35.7	786	0.13		1.00	4.70	118
G-38	37-38	10.32	12.2	0.19	82.1	33.8	5.84	22.0	541	146	36.1	784	0.11		0.86	5.10	117
G-39	38-39	11.57	15.2	0.17	71.8	30.0	6.07	19.6	478	143	32.5	714	0.14		0.70	4.80	103

NOAA Sediments
Core-G

Sample	Depth (cm)	Aluminum %	Arsenic ppm	Cadmium ppm	Chromium ppm	Copper ppm	Iron %	Lead ppm	Manganese ppm	Mercury ppb	Nickel ppm	Phosporus ppm	Silver ppm	Selenium ppm	Antimony ppm	Tin ppm	Zinc ppm
G-40	39-40	11.57	15.8	0.15	78.5	30.8	5.78	23.0	549	140	34.1	799	0.10		0.69	4.50	116
G-41	40-41	12.42	10.5	0.12	84.3	28.1	5.56	32.0	568	144	33.3	803	0.09		0.68	3.80	120
G-42	41-42	12.03	15.9	0.15	73.4	28.3	5.80	24.8	555	142	32.7	718	0.13		0.66	4.60	105
G-43	42-43	11.44	23.8	0.14	78.8	33.8	6.11	26.2	601	143	33.6	790	0.13		0.68	4.50	113
G-44	43-44	11.90	12.6	0.15	66.9	29.9	6.37	17.5	533	146	29.1	623	0.12		0.59	4.30	100
G-45	44-45	11.57	16.3	0.15	70.9	31.2	5.93	19.2	546	149	30.7	329	0.12		0.62	4.30	101
G-46	45-46	11.49	11.5	0.14	75.9	32.5	5.82	26.2	581	142	33.8	808	0.09		0.96	4.20	110
G-47	46-47	11.50	9.1	0.18	79.7	36.4	5.67	31.0	538	144	32.9	777	0.13		0.82	4.30	115
G-48	47-48	11.46	15.7	0.12	72.9	33.7	5.64	26.2	503	147	33.4	719	0.21		0.90	3.90	107
G-49	48-49	13.06	14.4	0.10	88.1	29.3	5.67	38.2	469	146	37.7	827	0.16		0.82	3.51	133
G-50	49-50	11.37	20.9	0.14	76.2	33.3	5.65	32.8	389	144	33.9	754	0.13		0.90	4.40	112
G-51	50-51	11.95	15.0	0.13	72.0	32.8	5.49	26.8	340	148	32.5	679	0.11		0.69	4.10	106

NOAA Sediments
Core-H

Sample	Depth (cm)	Aluminum %	Arsenic ppm	Cadmium ppm	Chromium ppm	Copper ppm	Iron %	Lead ppm	Manganese ppm	Mercury ppb	Nickel ppm	Phosporus ppm	Silver ppm	Selenium ppm	Antimony ppm	Tin ppm	Zinc ppm
H-0	0-1	9.10	9.0	0.29	71.6	24.0	4.11	40.4	432	118	23.3	1,097	0.27	0.32	0.60	3.50	100
H-019	19-20	9.63	14.3	0.38	85.4	28.2	4.50	19.9	253	126	24.7	637	0.35		0.93	4.60	99
H-039	39-40	9.89	14.9	0.37	09.6	27.0	4.73	23.2	306	141	25.1	797	0.31	0.32	0.72	4.80	110
H-060	60-65	10.60	10.4	0.36	25.5	31.0	4.73	28.2	329	219	26.4	888	0.31		0.60	4.90	111
H-080	80-85	9.89	10.8	0.43	31.8	32.5	5.18	31.1	334	480	25.7	876	0.29	0.36	0.59	4.30	107
H-100	100-105	11.12	10.3	0.36	24.1	30.4	4.40	54.5	225	178	27.4	724	0.36		0.83	4.70	106
H-120	120-125	12.03	10.6	0.34	07.9	31.3	5.71	51.0	419	182	27.9	907	0.34	0.47	0.63	4.50	99
H-135	135-140	12.04	19.6	0.30	01.8	28.8	5.87	52.9	497	175	29.9	1,071	0.23		0.60	4.70	95
H-160	160-165	12.61	8.3	0.28	84.0	34.3	5.96	64.2	584	207	29.8	927	0.26		1.13	5.00	100
H-180	180-185	13.01	10.5	0.24	85.0	32.8	6.13	50.7	635	189	30.9	923	0.21	0.24	0.90	4.80	110
H-200	200-210	12.55	10.6	0.27	76.2	32.7	6.33	48.4	822	163	30.3	907	0.21		0.60	4.20	96
H-230	230-240	14.31	10.1	0.30	73.8	38.5	6.70	55.3	1,109	179	34.1	873	0.29	0.35	0.67	4.60	104
H-255	255-265	13.98	7.8	0.20	75.7	35.7	6.79	49.0	1,088		32.4	898	0.21		0.59	4.50	100
H-325	325-335	15.67	8.1	0.19	70.8	37.9	7.30	49.2	832		34.2	843	0.19		0.71	4.70	93
H-395	395-405	14.18	10.6	0.22	76.7	38.0	7.10	46.0	981		32.2	975	0.20		0.64	4.50	100
H-465	465-475	14.88	13.0	0.24	70.8	38.2	6.79	44.0	941		33.3	871	0.17		0.61	4.40	91
H-515	515-525	14.26	12.9	0.20	75.9	35.4	6.92	43.8	961		33.1	919	0.19		0.46	4.10	94

NOAA Sediments
Core-L

Sample	Depth (cm)	Aluminum %	Arsenic ppm	Cadmium ppm	Chromium ppm	Copper ppm	Iron %	Lead ppm	Manganese ppm	Mercury ppb	Nickel ppm	Phosporus ppm	Silver ppm	Selenium ppm	Antimony ppm	Tin ppm	Zinc ppm
L1-01-2	1-2	11.05	0.1	0.14	75.9	33.0	5.13	58.3	627	55	28.5	701	0.18		0.38	3.32	87
L1-06-7	6-7	10.62	2.6	0.16	79.5	38.6	4.83	81.2	531	58	29.6	706	0.18		0.39	3.52	88
L1-10-11	10-11	10.95	0.6	0.18	77.4	51.5	4.84	24.1	567	63	28.5	806	0.21		0.41	3.62	93
L1-15-16	15-16	11.12	2.5	0.14	79.9	34.8	6.24	54.9	1,149	49	29.7	787	0.15		0.37	3.31	89
L1-20-21	20-21	11.12	3.3	0.15	79.3	72.1	5.54	60.7	891	76	28.9	846	0.20		0.43	3.46	87
L1-25-26	25-26	11.74	0.1	0.14	79.0	32.8	4.74	37.1	482	66	30.2	743	0.16		0.40	3.53	94
L1-30-31	30-31	11.72	2.8	0.19	76.8	44.0	4.86	81.1	506	66	31.9	912	0.18		0.43	3.77	100
L1-35-36	35-36	11.38	1.7	0.18	71.6	39.0	4.80	62.1	668	64	27.6	762	0.17		0.42	3.66	102
L1-40-41	40-41	11.43	1.2	0.17	75.2	33.0	4.95	07.0	794	74	28.3	779	0.17		0.36	3.42	93
L1-45-46	45-46	10.23	1.8	0.18	77.0	28.1	5.35	33.5	1,125	55	26.0	837	0.16		0.33	3.14	86

NOAA Sediments
Core-M

Sample	Depth (cm)	Aluminum %	Arsenic ppm	Cadmium ppm	Chromium ppm	Copper ppm	Iron %	Lead ppm	Manganese ppm	Mercury ppb	Nickel ppm	Phosporus ppm	Silver ppm	Selenium ppm	Antimony ppm	Tin ppm	Zinc ppm
M-01	0-1	4.62	5.0	0.06	36.6	6.2	2.05	17.8	320	23	8.2	366	0.07	0.33	0.04	0.10	47
M-02	1-2	4.33	5.1	0.05	33.2	4.7	1.65	15.8	266	17	6.6	354	0.07		0.01	0.10	41
M-03	2-3	4.31	2.4	0.06	30.4	4.9	1.64	12.2	239	17	6.0	329	0.06	0.33	0.01	0.05	42
M-04	3-4	4.37	6.1	0.07	35.3	6.4	1.82	15.9	230	21	7.7	677	0.09		0.14	1.00	48
M-05	4-5	5.21	5.2	0.09	43.5	8.1	2.23	14.3	244	29	10.6	699	0.11	0.35	0.14	1.20	52
M-06	5-6	5.51	12.4	0.10	48.5	9.3	2.55	20.2	257	34	12.8	765	0.13		0.20	1.60	57
M-07	6-7	5.53	9.3	0.14	47.6	9.1	2.65	17.7	259	35	10.7	622	0.13	0.79	0.11	0.50	56
M-08	7-8	5.20	7.7	0.05	44.5	8.3	2.38	13.4	254	30	9.9	396	0.09		0.04	0.05	52
M-09	8-9	4.78	9.0	0.06	39.9	6.6	2.16	17.6	237	27	8.0	550	0.11	0.33	0.06	0.20	48
M-10	9-10	5.00	7.9	0.08	40.4	7.7	2.01	15.2	228	25	8.6	696	0.11		0.15	1.20	50
M-11	10-11	4.99	7.3	0.07	39.7	7.0	2.17	11.8	228	24	7.7	708	0.10	0.10	0.12	0.90	49
M-12	11-12	4.95	7.2	0.09	40.5	7.3	2.08	16.8	234	25	9.0	724	0.11		0.18	1.20	48
M-13	12-13	5.22	5.9	0.05	41.4	7.1	2.23	11.8	240	28	8.6	435	0.08	0.10	0.04	0.05	52
M-14	13-14	5.22	8.4	0.07	44.1	7.8	2.39	12.0	254	30	9.3	578	0.11		0.10	0.50	51
M-15	14-15	4.89	9.6	0.07	42.3	7.8	2.36	12.6	266	31	8.7	666	0.11	0.10	0.12	0.80	50
M-16	15-16	5.32	10.5	0.12	45.9	8.7	2.35	14.6	271	33	19.1	737	0.13		0.19	1.40	56
M-17	16-17	4.96	20.3	0.06	43.7	3.7	2.32	11.5	259	36	14.1	596	0.12		0.18	0.70	55
M-18	17-18	5.21	9.9	0.09	48.1	8.7	2.39	9.1	255	38	15.2	745	0.13		0.21	1.50	57
M-19	18-19	6.04	11.5	0.11	52.0	9.5	2.70	7.9	252	44	14.6	672	0.13	0.19	0.23	1.60	62
M-20	19-20	5.98	12.7	0.12	52.3	9.9	2.76	8.2	267	44	13.1	700	0.13		0.25	1.80	63

NOAA Sediments
Core-M

Sample	Depth (cm)	Aluminum %	Arsenic ppm	Cadmium ppm	Chromium ppm	Copper ppm	Iron %	Lead ppm	Manganese ppm	Mercury ppb	Nickel ppm	Phosporus ppm	Silver ppm	Selenium ppm	Antimony ppm	Tin ppm	Zinc ppm
M-21	20-21	6.28	9.7	0.11	59.8	12.1	3.09	10.1	276	52	15.5	672	0.13	0.10	0.26	1.80	68
M-22	21-22	6.60	15.1	0.12	62.8	12.6	3.27	12.2	286	64	17.4	730	0.14		0.27	2.10	72
M-23	22-23	6.49	12.8	0.11	63.9	12.4	3.29	10.5	284	53	17.5	693	0.14	0.10	0.27	1.90	73
M-24	23-24	6.81	17.0	0.12	64.7	12.5	3.16	9.4	287	58	16.9	768	0.14		0.27	2.10	71
M-25	24-25	6.70	13.8	0.10	58.9	10.7	3.18	10.7	289	59	16.0	763	0.13	0.10	0.25	1.90	68
M-26	25-26	6.56	33.9	0.10	56.1	10.0	3.01	12.9	285	46	13.3	702	0.14		0.20	1.40	66
M-27	26-27	6.03	11.6	0.09	55.0	10.2	2.86	9.4	283	50	13.1	675	0.13	0.22	0.18	0.70	63
M-28	27-28	6.14	12.3	0.12	56.9	10.8	2.91	8.1	296	53	12.1	769	0.16		0.26	1.90	65
M-29	28-29	6.29	27.4	0.09	60.9	10.1	3.01	10.1	291	51	14.2	662	0.15	0.26	0.16	0.80	68
M-30	29-30	6.71	16.8	0.12	61.5	12.2	3.11	8.5	281	53	14.4	759	0.15		0.25	2.00	70
M-31	30-31	6.06	13.5	0.16	56.1	10.8	2.88	10.6	286		12.9	679	0.13		0.24	1.70	64
M-32	31-32	6.05	11.9	0.12	55.2	12.0	2.87	9.6	293		12.8	711	0.13		0.25	1.80	65
M-33	32-33	5.93	10.6	0.12	50.9	9.6	2.61	10.4	277		11.3	558	0.13		0.21	1.20	60
M-34	33-34	5.93	14.0	0.11	49.4	9.3	2.61	12.2	284		10.9	681	0.13		0.20	1.10	60
M-35	34-35	5.89	13.1	0.12	56.3	10.1	2.91	9.3	292		13.9	740	0.14		0.26	1.80	65
M-36	35-36	5.64	12.2	0.13	50.6	8.6	2.84	10.6	293		11.3	651	0.13		0.21	1.30	61
M-37	36-37	5.75	16.9	0.11	51.6	9.5	2.66	8.4	295		12.2	774	0.13		0.26	1.70	61
M-38	37-38	5.81	26.6	0.11	56.5	10.4	2.69	9.6	297		11.7	801	0.14		0.28	1.80	63
M-39	38-39	6.07	11.8	0.14	58.3	11.5	2.83	11.4	297		13.7	795	0.19		0.27	1.70	65

NOAA Sediments
Core-M

Sample	Depth (cm)	Aluminum %	Arsenic ppm	Cadmium ppm	Chromium ppm	Copper ppm	Iron %	Lead ppm	Manganese ppm	Mercury ppb	Nickel ppm	Phosporus ppm	Silver ppm	Selenium ppm	Antimony ppm	Tin ppm	Zinc ppm
M-40	39-40	6.09	13.6	0.12	57.9	10.7	2.92	11.2	295		14.8	860	0.15		0.26	1.70	66
M-41	40-41	5.63	12.7	0.11	58.3	13.0	3.00	13.2	285		15.2	876	0.13		0.25	1.70	64
M-42	41-42	6.07	15.2	0.12	55.9	11.7	2.99	12.1	289		15.6	753	0.14		0.27	1.80	67
M-43	42-43	6.11	11.7	0.09	49.1	10.6	2.44	12.5	272		14.6	766	0.13		0.22	1.60	59
M-44	43-44	5.40	9.7	0.10	45.2	9.6	2.39	9.0	264		13.3	707	0.12		0.21	1.40	56
M-45	44-45	5.42	12.6	0.08	44.4	9.3	2.48	9.6	259		12.1	642	0.11		0.17	1.30	56
M-46	45-46	5.71	11.5	0.09	50.9	10.8	2.72	9.6	279		14.8	696	0.15		0.21	1.50	62
M-47	46-47	5.81	10.4	0.09	64.5	13.4	2.68	14.9	356		19.1	911	0.13		0.19	1.60	78
M-48	47-48	5.19	10.5	0.07	44.0	8.5	2.42	11.5	284		11.3	704	0.13		0.16	0.90	56
M-49	48-49	5.50	11.4	0.10	48.7	10.1	2.51	10.0	281		13.2	707	0.14		0.23	1.70	60
M-50	49-50	5.39	8.8	0.09	44.1	9.2	2.39	7.8	278		13.2	703	0.12		0.19	1.40	58
M-51	50-51	5.43	10.2	0.08	49.2	10.4	2.40	11.3	281		14.0	742	0.12		0.21	1.60	62
M-52	51-52	5.50	11.5	0.11	52.1	11.0	2.83	9.9	279		14.6	761	0.14		0.24	1.80	64
M-53	52-53	5.69	10.6	0.11	50.3	10.6	2.71	9.3	269		14.0	720	0.11		0.23	1.80	63